U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
NATIONAL METEOROLOGICAL CENTER

OFFICE NOTE 366

"GLOBAL MODEL FORECASTS OF THE GREAT BRITISH STORM OF 25 JANUARY 1990"

BRADLEY A. BALLISH

APRIL 1990

Introduction

On the 25th of January, 1990 a severe storm hit Great Britain causing over a billion dollars in damage as well as dozen of deaths. This storm is of interest due to its great destruction but also for some scientific reasons. In 24 hours, the storm deepened more than 30 mb and thus can be considered a bomb, Sanders and Gyakum (1980). Despite rapid development and movement that would normally be difficult to predict, the European Centre predicted the storm 5 days in advance very well. The European Forecasts 3 and 4 days in advance were not as good as their previous 5 day forecast, and their 2 day forecast was even less skillful. NMC's global model did not do well prior to 84 hours in advance of the storm, however, NMC's forecasts for 12 to 84 hours in advance were consistently excellent every 12 hours. The British global forecast 48 hours in advance was not very good, similar to the European 48 hour forecast, while all three centers did fairly well 24 hours in advance.

This paper shows NMC final analyses for 1200 GMT, 25 January, 1990, the time of the great storm, as well as a sequence of previous maps indicating how the storm developed. Next we examine how different global models performed at predicting the storm. Then we show that when the middle atmospheric depression or vortex was over the United States our analyses did not have heights as low as nor a circulation as strong, as shown by radiosonde data.

However, when the system got over the Atlantic, NMC's forecast skill improved.

The Observed Storm and its Development

For 1200 GMT 25 January, 1990, Fig. 1a shows 1000 mb heights derived from rhomboidal 40 resolution spectral coefficients from the NMC final analysis, Dey and Morone (1985). Figure 1b shows the same except at 500 mb. The 1000 mb map shows a very deep low with a very tight height gradient over southern England. At 500 mb we see a modest depression imbedded in a strong westerly flow. Figures 2a and 2b show 1000 mb and 850 mb wind speeds from the same NMC analysis as above. With a large scale global analysis showing 30 m/sec winds at 1000 mb and 40 m/sec at 850 mb, it would not be surprising that instantaneous gusts of wind could be stronger yet and very destructive.

Twelve hours earlier than the above time, Figs. 3a and 3b show respectively NMC's final analysis 1000 mb and 500 mb heights. At a little north of 50^{o} and about 15^{o} west, the 1000 mb map shows a surface low that will deepen 150 meters in the next 12 hours. At 500 mb, we see a short wave west of the surface low. This wave imbedded in strong westerlies will have strong differential vorticity advection which will help the surface low deepen further.

At 1200 GMT 24 January, 1990, Figs. 4a and 4b show NMC's 1000 mb and 500 mb height analyses respectively. Now the surface low is at roughly 50^{o} North and 35^{o} West. In the next 24 hours the surface low will move half way across the Atlantic and deepen 330 meters, a bomb. At this time, the 500 mb map indicates a wave west of the surface low at about 50^{o} West.

Figures 5a and 5b show similar maps 12 hours earlier valid 0000 GMT 24 January, 1990. The 1000 mb height at the center of surface low is about 90 meters higher than 12 hours later in time. Again the 500 mb wave is still west of the surface low.

Twelve hours earlier, Figs. 6a and 6b similarly show the surface low is weaker centered at roughly 65^{o}W and 45^{o}N. The wave at 500 mb is now roughly at 70^{o}W. While in Figs. 7a through 10b we can see the wave at 500 mb being further west every 12 hours, however, it is difficult to see any signs of a surface low. In Fig. 11 we see a cut-off low at 500 mb at 0000 GMT 21 January, 1990, that 12 hours later becomes a sharp wave in the westerly flow shown in Fig. 10b. In section 4 of this paper, we will examine in more detail how our analysis performed with this cut-off low.

Global Forecasts of the Storm

First we examine forecasts from the European Centre for Medium Range Forecasts. Note that their forecasts are sent to NMC on a $2\frac{1}{2}^{\circ}$ by $2\frac{1}{2}^{\circ}$ grid at 1000 mb and 500 mb only. Unfortunately, for what ever reason, these gridded fields are interpreted to a 5° by 5° grid. These 5° by 5° values are later interpreted to a $2\frac{1}{2}^{\circ}$ by $2\frac{1}{2}^{\circ}$ grid which is then archived on disk for a period of 36 days. However, the storm is large enough that such interpolations will not degrade the results excessively. The European 6 day forecast at 1000 mb and 500 mb is shown in Figs. 12a and 12b respectively. These maps give some indication of a possible storm, but the surface low is too weak and too far out to sea. The 500 mb through has too much amplitude and again is too far to the west.

The European 5 day forecast is similarly shown in Figs. 13a and 13b. For the unusual storm, their 5 day 1000 mb forecast is quite successful. It shows a deep surface low in approximately the right location, but only 2/3 as deep as the observed storm. The 500 mb trough is somewhat too far to the west.

The European 4 day forecast for this storm is similarly shown in Figs. 14a and 14b. Their 500 mb forecast is improved over their 5 day forecast, however, the 1000 mb forecast looks more like a trough with strong westerly winds moving around the Icelandic low. Their 3 day 1000 mb forecast is similar, Fig. 15, while their 2 day 1000 mb forecast has a trough that is too weak and spread out too much in the east-west direction, Fig. 16. Their 1 day forecast 1000 mb, Fig. 17, looks much better but is not deep enough, possibly due to the grid interpolations mentioned earlier.

NMC's forecasts of the storm are now examined. The model used has 18 levels in the vertical, with T80 spectral horizontal resolution, Sela (1982) and more recently Sela (1988). Our 5½ day, or 132 hour, forecasts at 1000 mb and 500 mb respectively are shown in Figs. 18a and 18b. These forecasts have no skill or use at indicating a storm over England. Our 4½ day, or 108 hour forecast, is shown similarly in Figs. 19a and 19b. These indicate a significant storm, but 30^{o} West of the observed storm.

NMC's first skillful forecast of the storm occurs 84 hours, or 3½ days in advance, see Figs. 20a and 20b. The 500 mb forecast is much better, while at 1000 mb the forecast has a deep low, -240 m versus -330 m observed. The surface forecast has a tight height gradient in southern England but lacks the cyclonic curvature shown in the verifying analysis Fig. 1a.

NMC's global model showed some skill at 84 hours but did not become excellent until 72 hours in advance, see Fig. 21. Our global model continued to produce excellent 1000 mb forecasts every 12 hours from that time on, see Figs. 23-26.

Due to technical problems, we only received, at NMC, two British Meteorology Office forecasts valid 1200 GMT 25 January, 1990, Figure 27 shows their 48 hour 1000 mb forecast for this storm. With their 1000 mb low being 150 meters to weak. At 24 hours, their 1000 mb forecast is improved but is roughly 90 meters too weak, Fig. 28.

Diagnostics on NMC's Analyses

Figure 11 showed a cutoff low at 500 mb over Iowa at 0000 GMT 21 January, 1990, and now we look at how this low was analyzed back further in time. In Fig. 29 a we have a map showing 300 mb heights of NMC's first-guess valid 0000 GMT 20 January, 1990. In addition, it shows values of height residuals at radiosonde locations, where a residual is data minus guess values. The cut-off low in the guess has heights that are reasonably close to the observed values. In Fig. 29b we show the same guess heights, but now the residuals are based on wind values, in m/sec. If we look at the wind residuals of the nearest 6 radiosonde reports, roughly on an egg shaped ellipse with its longest axis in approximately an east-west direction, we see that the data have more cyclonic circulation then does the guess. Similar but weaker residual patterns were also at 500 and 400 mb. Similarly in Figs. 30a and 30b we show analysis height plus height and wind residuals respectively. Similar to the guess, the analysis has no significant height residuals near the center of the cut-off low. However, the analysis still does not appear to have as much cyclonic circulation as does the six radiosondes surrounding it. Thus if the radiosonde winds are accurate, we may expect the model's guess for 1200 GMT 20 January, 1990 to have a cut-off low that is too weak.

Now we show the first-guess at 1200 GMT 20 January 1990 with its height and height residuals at 500, 400, and 300 mb in Figs. 31a-33b. The guess cut-off low is too weak based on both height and wind residuals that show roughly a geostrophic pattern. This time, the buddy check rejected the wind data at 400 and 369 mb for Omaha, Nebraska as well as the 300 mb winds at North Platte, Nebraska. The operational buddy check is univariate, so that nearby wind residuals with a circular or cyclonic pattern appear to differ too much with each other. Now the analysis tends to show negative height residuals as well as a cyclonic pattern in wind residuals from 500 to 300 mb, shown only at 400 mb in Figs. 34a and 34b.

Not surprisingly, the guess at 0000 GMT 21 January, 1990 has cyclonic residuals as shown at 400 mb in Figs. 35a and

35b. This time the large residuals are concentrated near the intersection of Nebraska, Iowa, and Missouri. This time, the buddy check, in this vicinity, pitched only the large wind residual at Omaha at 400 mb. The analysis shown in Figs. 36a and 36b at 400 mb shows a large wind residual at Omaha and a large height residual of -57 meters in northeast Kansas.

By 1200 GMT 21 January, 1990 the guess shows that the cutoff low of previous interest has merged with the westerly flow and now is a trough near southern Michigan. Figs. 37a and 37b show 400 mb guess heights with height and wind residuals. We see height residuals of -66 m at Flint, Michigan and -58 m at Dayton, Ohio. The Flint radiosonde shows a wind residual of 20 m/sec in a direction geostrophically consistent with the above height residuals, but that residual was tossed by the buddy check. The analysis at this time does not significantly reduce the above residuals.

By 0000 GMT 22 January, 1990 the guess heights at 500 mb could be called a wave in the westerly flow. Figs. 38a and 38b show the 500 mb guess heights with height and wind residuals. The 15 m/sec wind residual at 500 mb in eastern New York was tossed by the buddy check even though the two height residuals at roughly 70° W and 42-44°N would geostrophically support it. The above residuals are reduced in the analysis shown in Figs. 39a and 39b. Note that at 400 mb, the height residuals for the above two radiosondes near 70°W were pitched in the buddy check for residuals of -58 m and -72m, even though they support each other and are supported by a 15 m/sec wind residual in eastern New York. After this analysis time, the wave at 500 mb is far enough east not to be affected significantly by the analysis use of radiosonde data over North America. From this time on, the most important data for forecasting the storm over England will be ship data and satellite temperature soundings.

NMC's Surface Data Usage

NMC's surface data base has two special features. First, NMC has a large number of surface "Bogus" observations, which are values of pressure at mean sea level produced by human analysts. For example, with the case of 0600 GMT 24 January, 1990, Fig. 40 gives NMC's final analysis 1000 mb heights with data overlaid. The many black "X" are bogus locations, with their value of pressure in mb plotted to the upper right of the "X". The "cross-like" objects with wind flags are surface ship observations. The second special feature of our surface data base is that OPC, Ocean Product Center, does extensive quality control of the ship observations. They can put keep or hold flags on the ship data. Ship data that get a purge flag are removed in the OI data preprocessor and are never seen by the analysis code.

Ship data that receive a keep flag cannot be removed by any of the analysis quality control steps. For example, the analysis shown in Fig. 40, is also shown in Fig. 41, but this time the only data shown is the surface ships before OPC has removed any data. One key difference in this map, compared to Fig. 40, is at roughly 50^{O}W and about 41^{O}N. The ship with south-westerly winds in this area right next to a different ship with north-westerly winds was purged by OPC.

The ship at about 33^{O}W and 38^{O}N that has winds blowing across the isobars was never seen by the analysis code because the data preprocessor did not accept it because it did not have a pressure report. For some possible key reports near the surface low, OPC had keep flags on the pressure data. These keep flags applied to the ships at roughly (40^{O}W, 47^{O}N), (39^{O}W, 41^{O}N), (46^{O}W, 48^{O}N), and (37^{O}W, 52^{O}N). Our final analysis for this date was run experimentally with no purge flag on the ship, mentioned earlier, at roughly 49^{O}W, and 41^{O}N. Having two nearby observations that differ significantly can cause analysis problems, but in this case there was little change compared to the original final analysis, even though neither ship was removed by the quality control.

For the above analysis case, the analysis was rerun with diagnostic printouts turned on in the vicinity of the 1000 mb surface low. In the actual 1000 mb analysis few of the surrounding ship observations with keep flags were used. The operational analysis at a given point can use up to 30 pieces of data and it is constrained to use 20 profile type observations if they are sufficiently close in distance. Profile observations could be radiosondes or satellite temperature soundings. In this case at 1000 mb, the analysis chose 20 satellite heights valid at 850 mb, 6 surface bogus, the pressure and two wind components from the ship close by at roughly, 40^{o}W, 47^{o}N, and one component of wind from a ship nearby. The 850 mb satellite height data are derived from a preliminary 1000 mb analysis, with no satellite sounding data, plus using the satellite temperatures to integrate up hydrostatically to give 850 mb heights. Thus more of the nearby ship data would affect the preliminary 1000 mb analysis, but satellite temperatures would still have some unreasonable impact on the final 1000 mb heights. This may seem incorrect to use 850 mb heights derived from satellite soundings for our 1000 mb analysis, however it has the practical benefit of reducing possible large low-level temperature changes due to a satellite sounding problem. Hollingsworth (personal communication) has noted that such low-level temperature problems have negative impact on their model.

The European Centre does not use human quality control on ships nor does it have surface bogus. Possibly that caused their drop in skill for 2 to 3 day forecasts of the storm of

25 January, 1990. It would be interesting to test NMC's data assimilation with no bogus data and no quality control for ship observations.

Conclusions

The European Centre made an excellent 5 day forecast of the great English storm of 25 January, 1990. Their forecast skill decreased especially 2 days prior to the storm, and then did well at 1 day. NMC's forecast beyond 84 hours, for this storm, were not useful. However at 84 hours our forecast was good. Every 12 hours from then on, we produced excellent forecasts of the storm. NMC received only 2 forecasts from the British global model for this case. Their 48 hour forecast was not that good, similar to the European, while the British 1 day forecast improved similar to the European.

When the 500 mb low or wave that was important for this storm was over the United States our analysis had both heights not as low as the radiosonde observations as well as a cyclonic wind circulation not as strong as in the observations. This was clearly in part due to a univariate buddy check that removed some wind or height observations that appeared to have some geostrophic consistency. When this occurs for a period of 48 hours in a data dense region, something is wrong. Analysis of other cases indicates that even with no buddy check problems we still can underdraw for geostrophic data residuals. <u>This may be a theoretical error in the analysis.</u> The analysis assigns radiosonde data error levels that are due to estimated measurement errors plus errors of representativeness. This later error takes into account that the real world has small scale turbulence, gravity waves, thunderstorms, etc., that cannot be used well in large scale geostrophic analyses. Such effects are present in the radiosonde observations, but tend to be filtered out by the analysis with its built in geostrophic modelling. But now, if the radiosonde data in part shows geostrophically related residuals, the analysis will under draw for them because the data error levels include estimates of true measurement error as well as errors of representativeness. This needs to be investigated further along with improved multivariate quality control.

NMC's forecast of this major storm got better as the system moved over the ocean. Review of the quality control of ship data by OPC in this event, shows that they are doing good work. Further tests of the assimilation system should be tried without their quality control.

Acknowledgements

The author is grateful to Crystal Alban for typing the manuscript and to Masao Kanamitsu and Hua-Lu Pan for generating and maintaining the map-launcher. David Plummer provided help for the McIDAS map making codes, and Dennis Keyser supplied a special code to run the data preprocessor that ignored a ship purge flag.

References

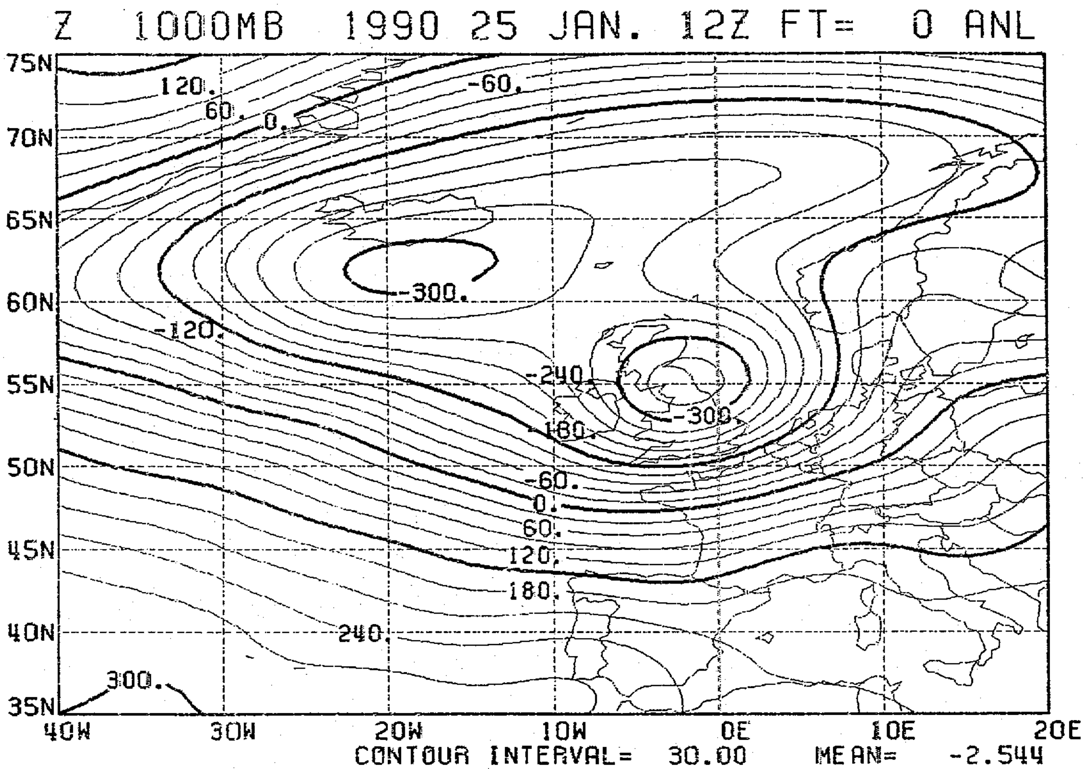
Dey, C. H., and L. L. Morone, 1985: Evolution of the National Meteorological Center Global Data Assimilation System: January 1982 - December 1983. Mon. Wea. Rev., 113, 304-318.

Sanders, F. and J. R. Gyakum, 1980: Synoptic-Dynamic Climatology of the "Bomb". Mon. Wea. Rev., 108, 1589-1606.

Sela, J. G., 1982: The NMC Spectral Model. NOAA Technical Report NWS30, National Meteorological Center, Washington, DC 20233

Sela, J. G., 1988: The new T80 NMC operational spectral model. Preprints, Eighth Conference on Numerical Weather Prediction (Baltimore, Md.), Amer. Meteor. Soc., 312-313.

(a)



(b)

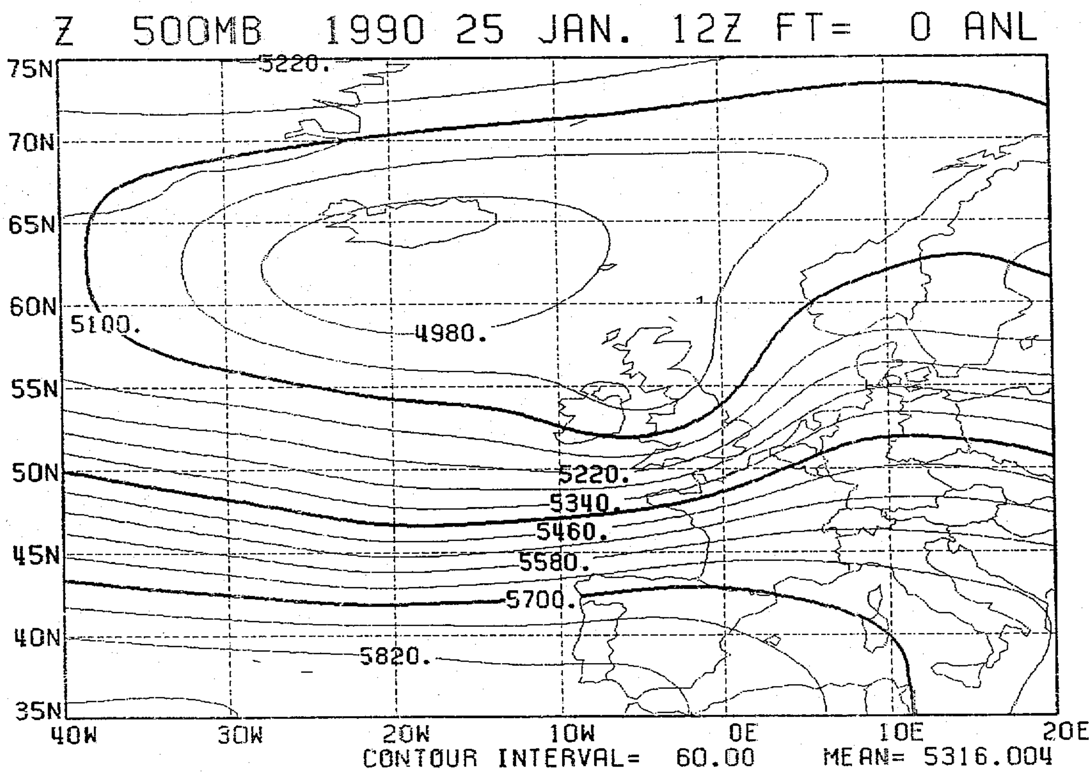


Fig. 1. NMC final analysis heights, 1200 GMT 25 January, 1990: (a) 1000 mb, (b) 500 mb.

(a)

(b)

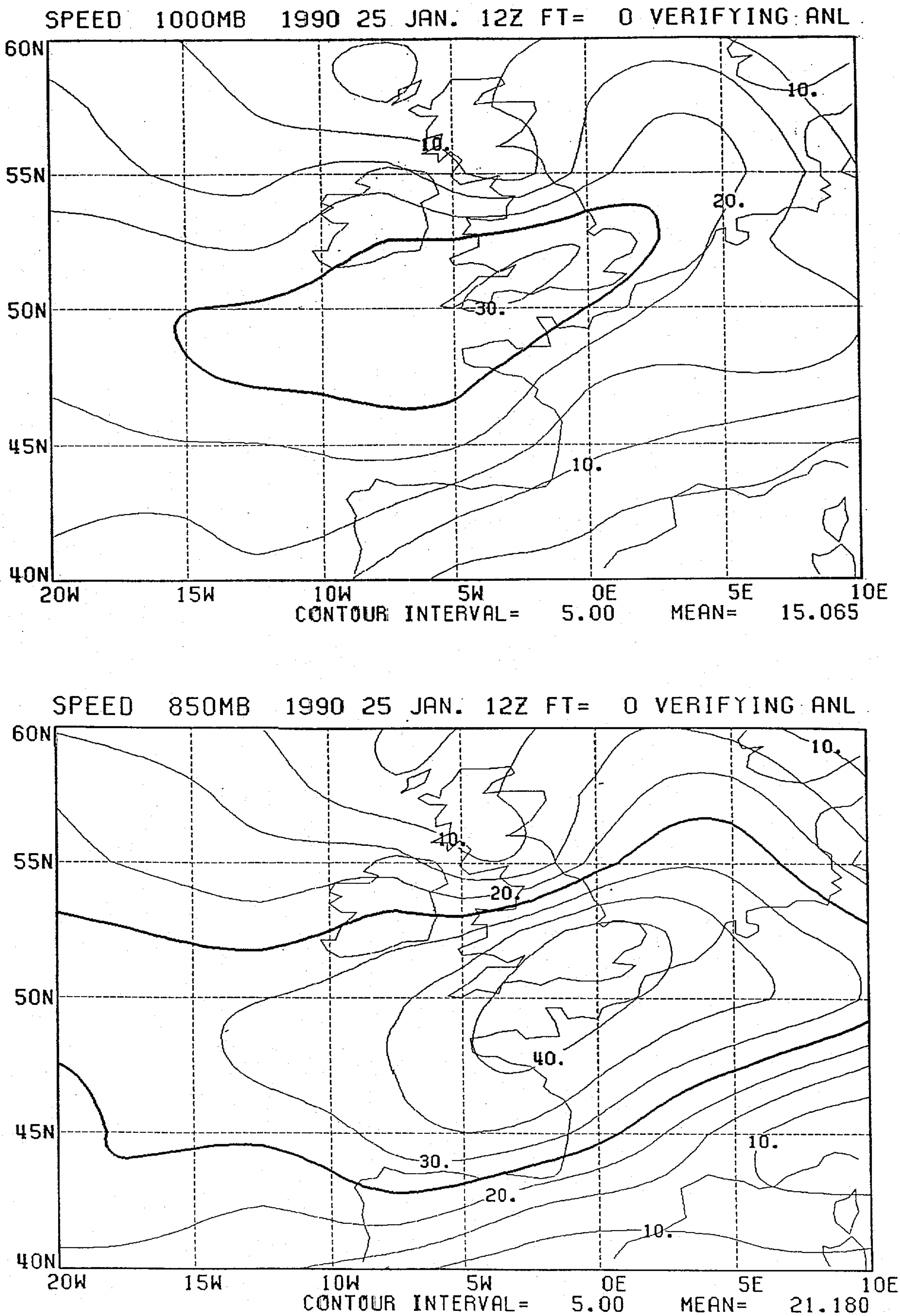


Fig. 2. NMC final analysis wind speed in m/sec 1200 GMT 25 January, 1990: (a) 1000 mb, (b) 850 mb.

(a)

(b)

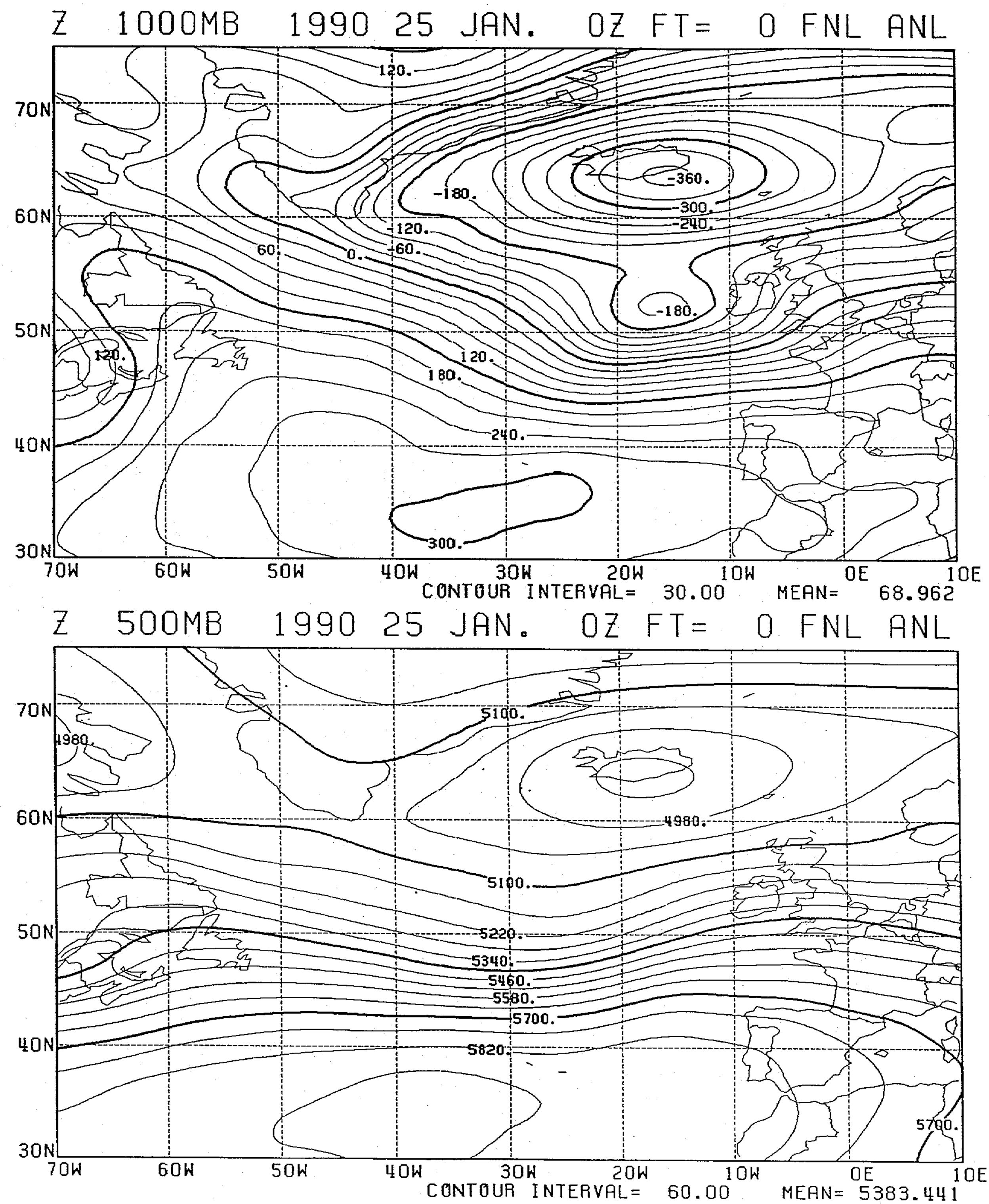


Fig. 3. NMC final analysis heights, 0000 GMT 25 January, 1990: (a) 1000 mb, (b) 500 mb.

(a)

(b)

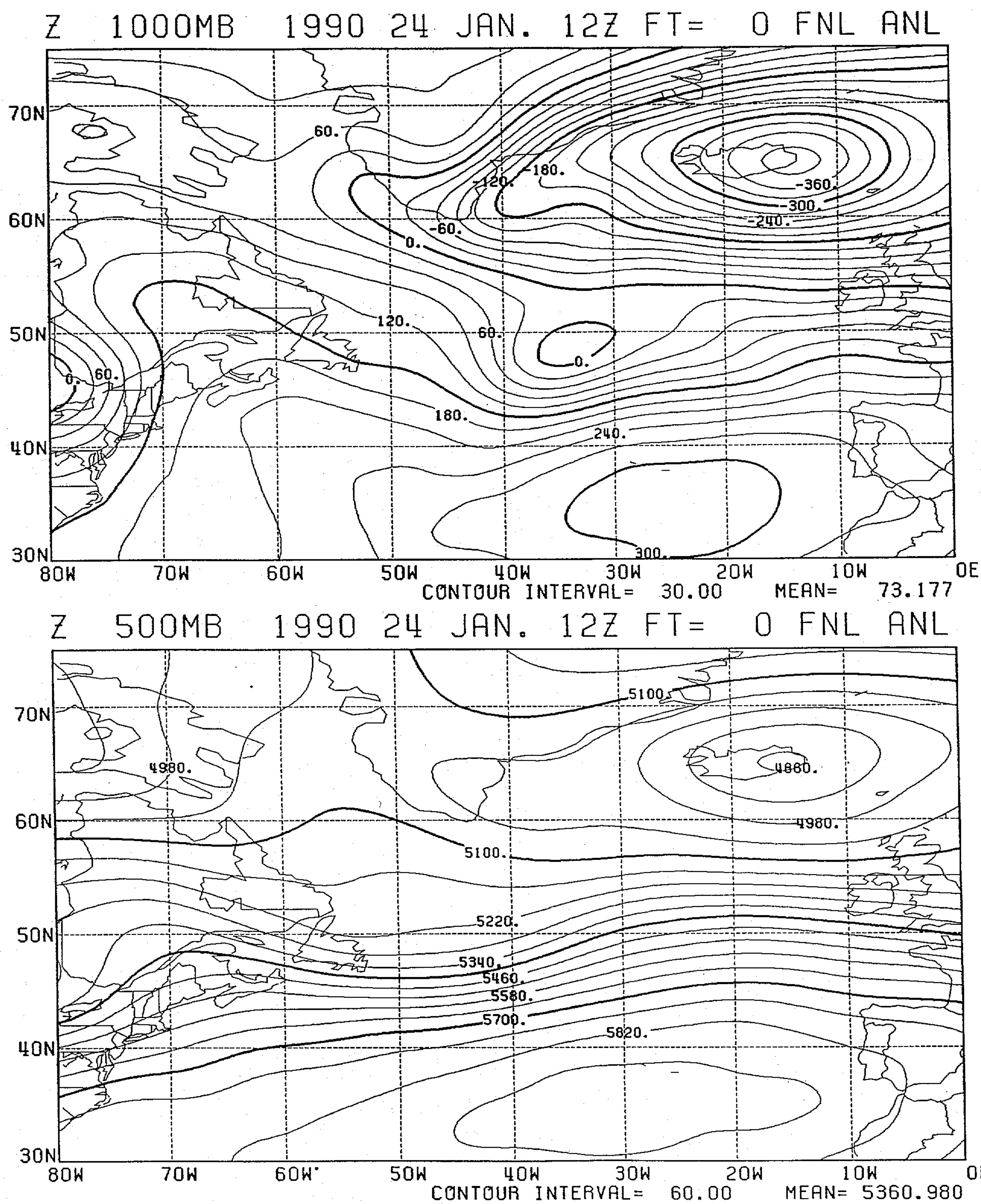


Fig. 4. NMC final analysis heights, 1200 GMT 24 January, 1990: (a) 1000 mb, (b) 500 mb.

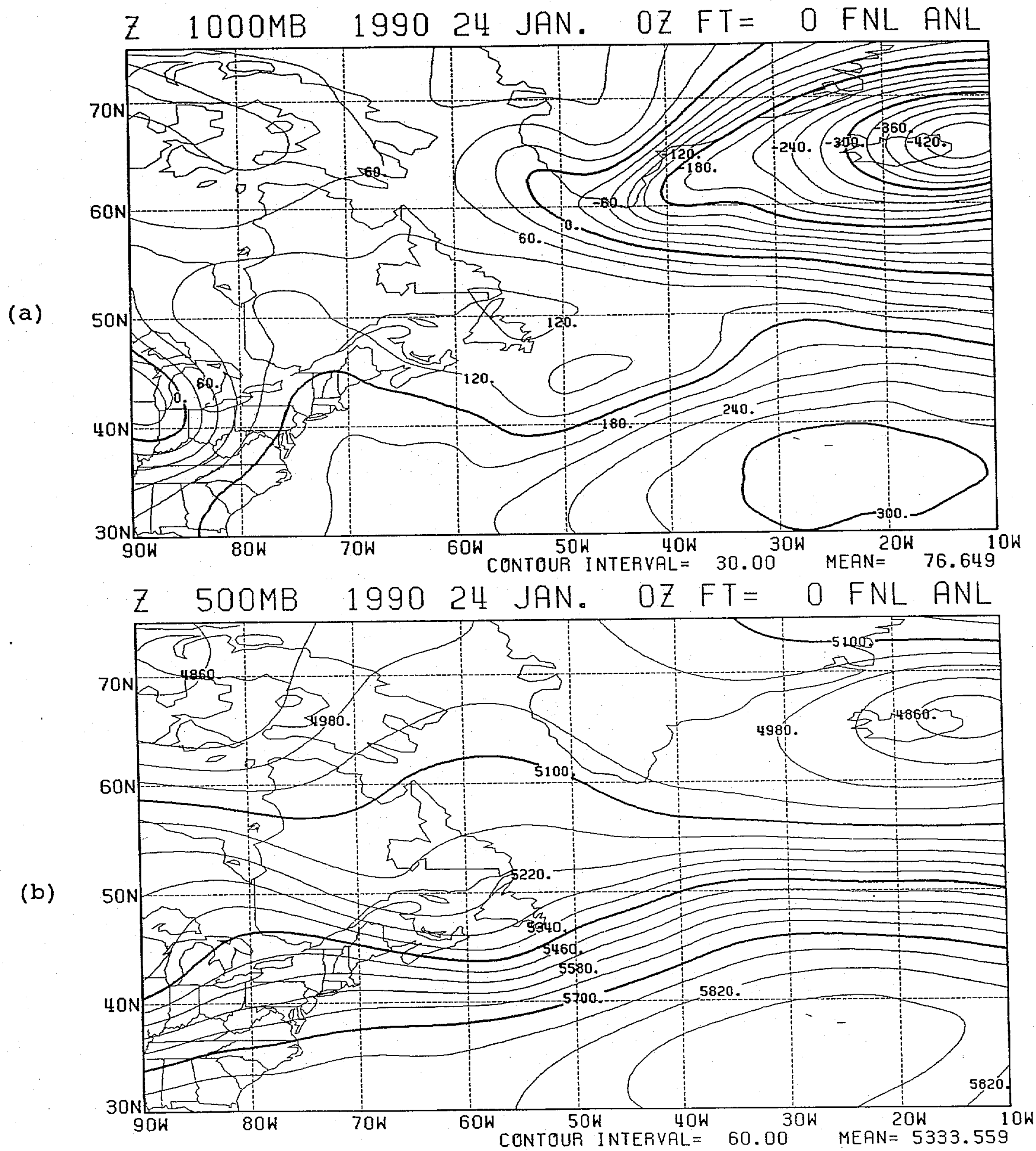
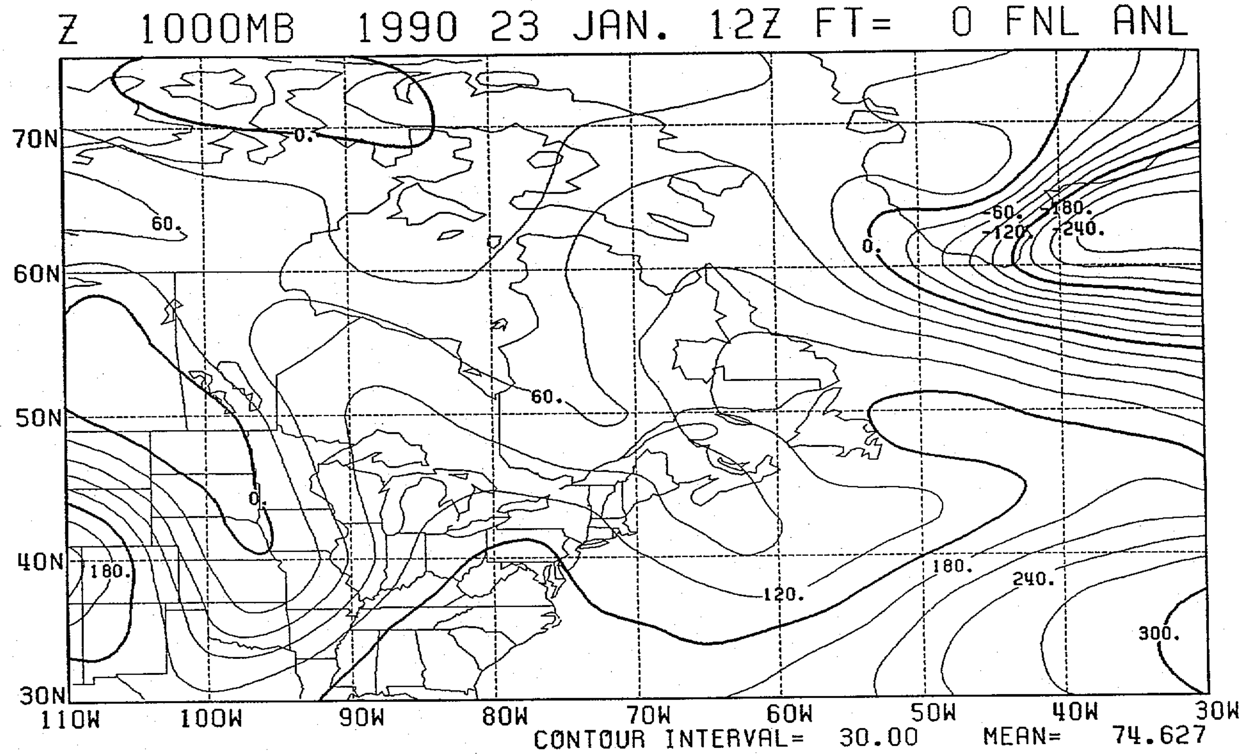


Fig. 5. NMC final analysis heights, 0000 GMT 24 January, 1900: (a) 1000 mb, (b) 500 mb.

(a)



(b)

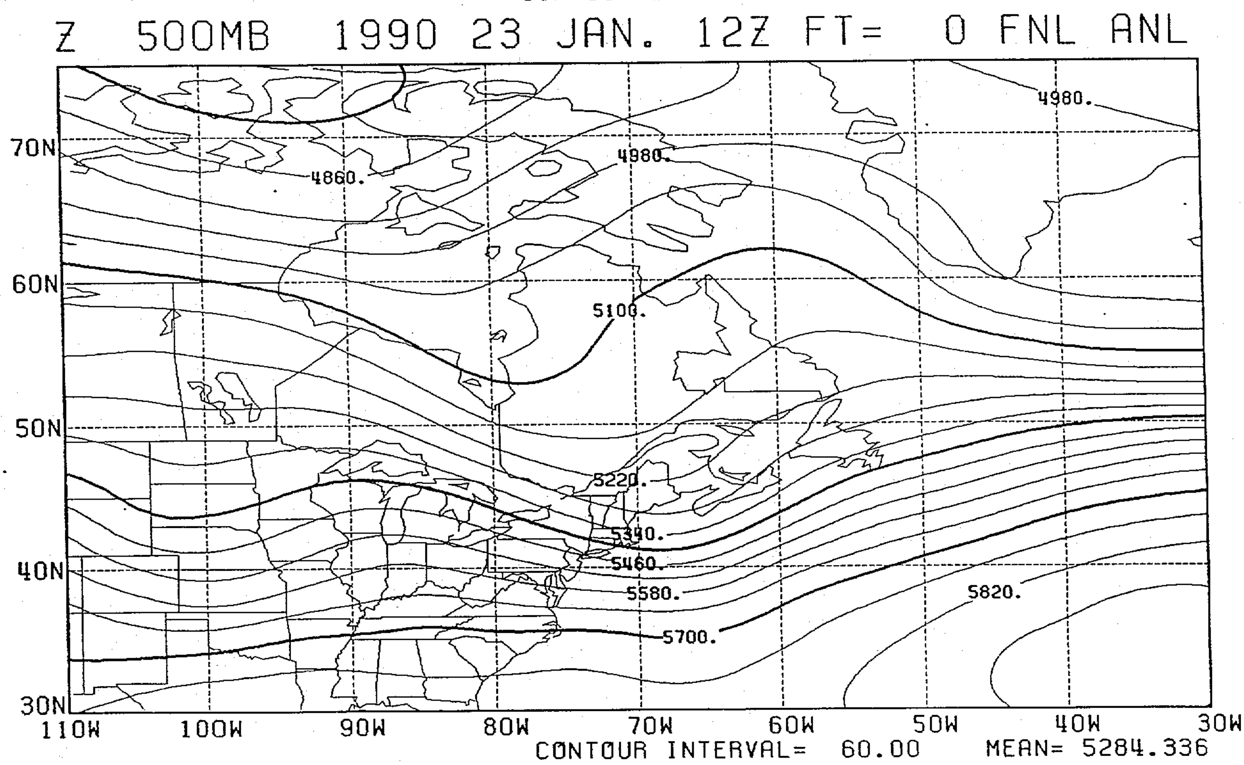


Fig. 6. NMC final analysis heights, 1200 GMT 23 January, 1990: (a) 1000 mb, (b) 500 mb.

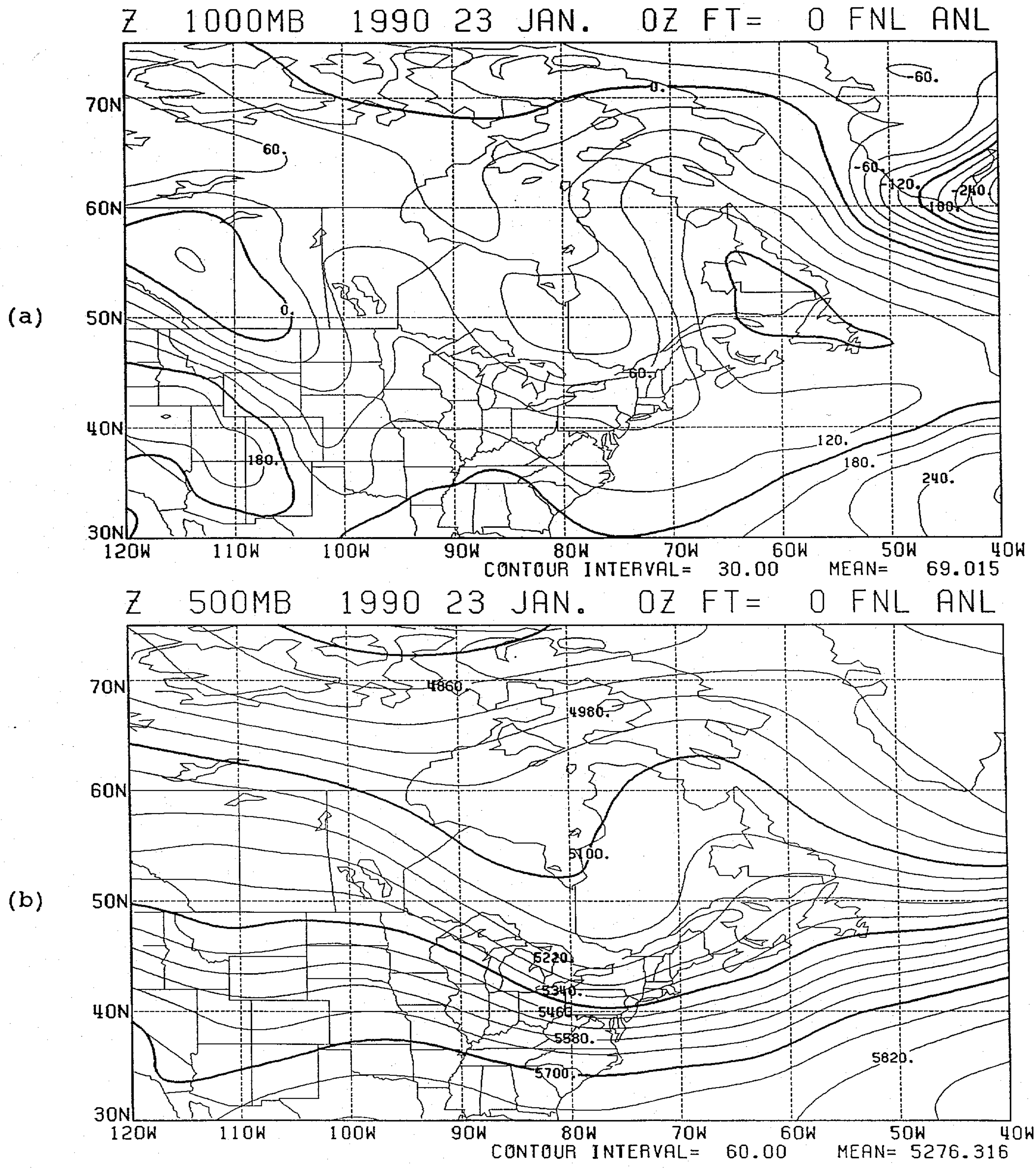


Fig. 7. NMC final analysis heights, 0000 GMT 23 January, 1990: (a) 1000 mb, (b) 500 mb.

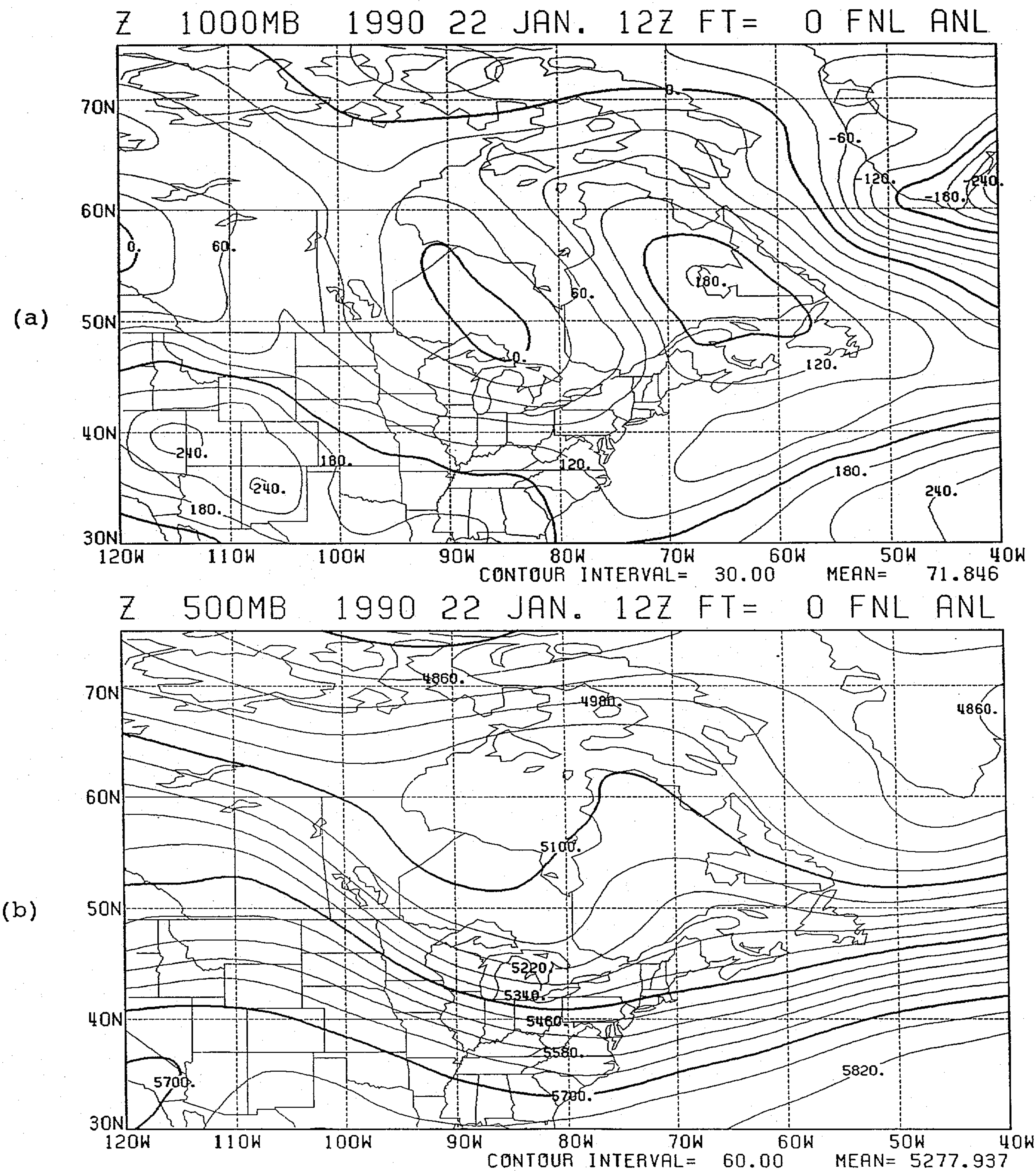


Fig. 8. NMC final analysis heights, 1200 GMT 22 January, 1990: (a) 1000 mb, (b) 500 mb.

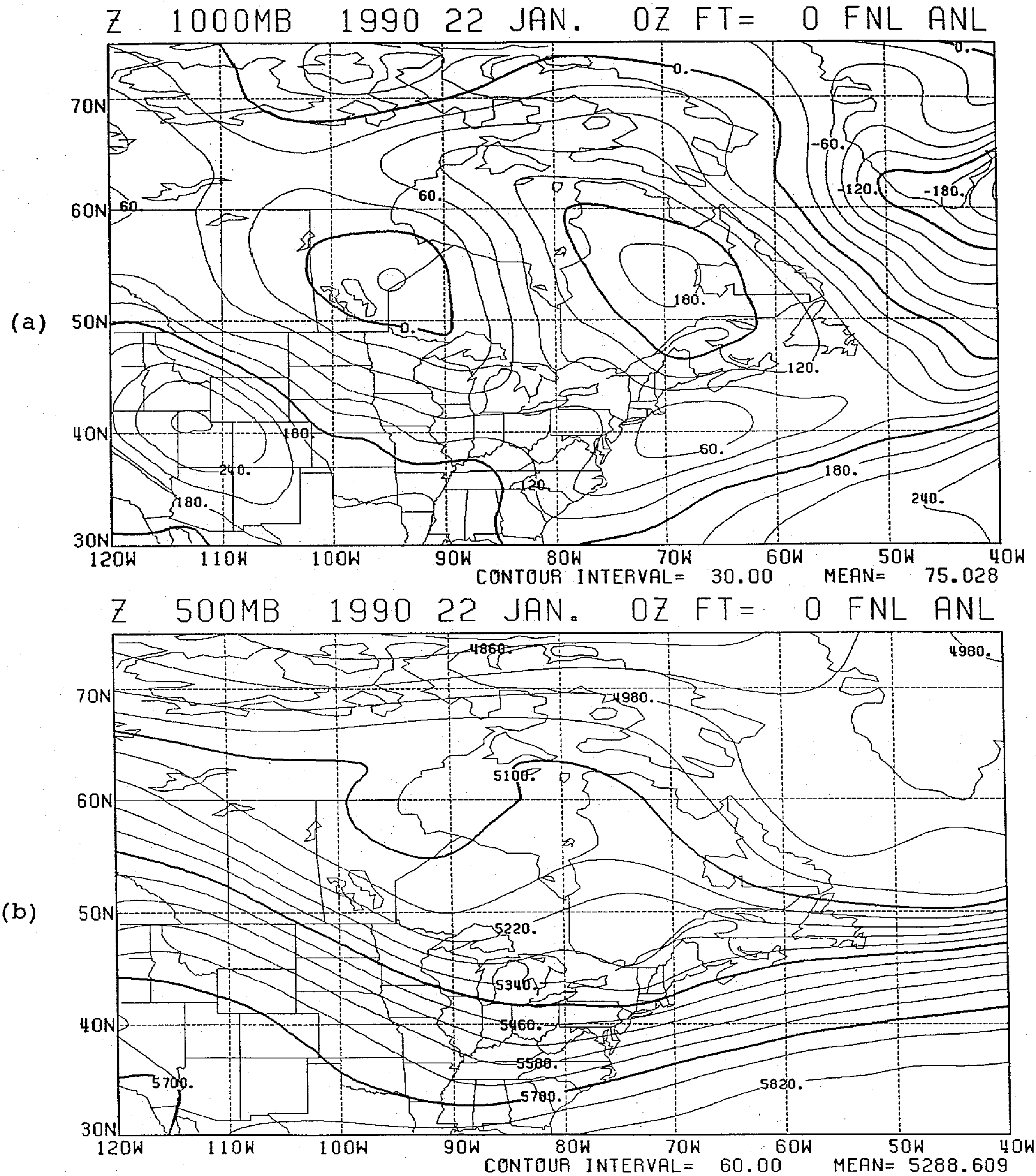


Fig. 9. NMC final analysis heights, 0000 GMT 22 January, 1990: (a) 1000 mb, (b) 500 mb.

(a)

(b)

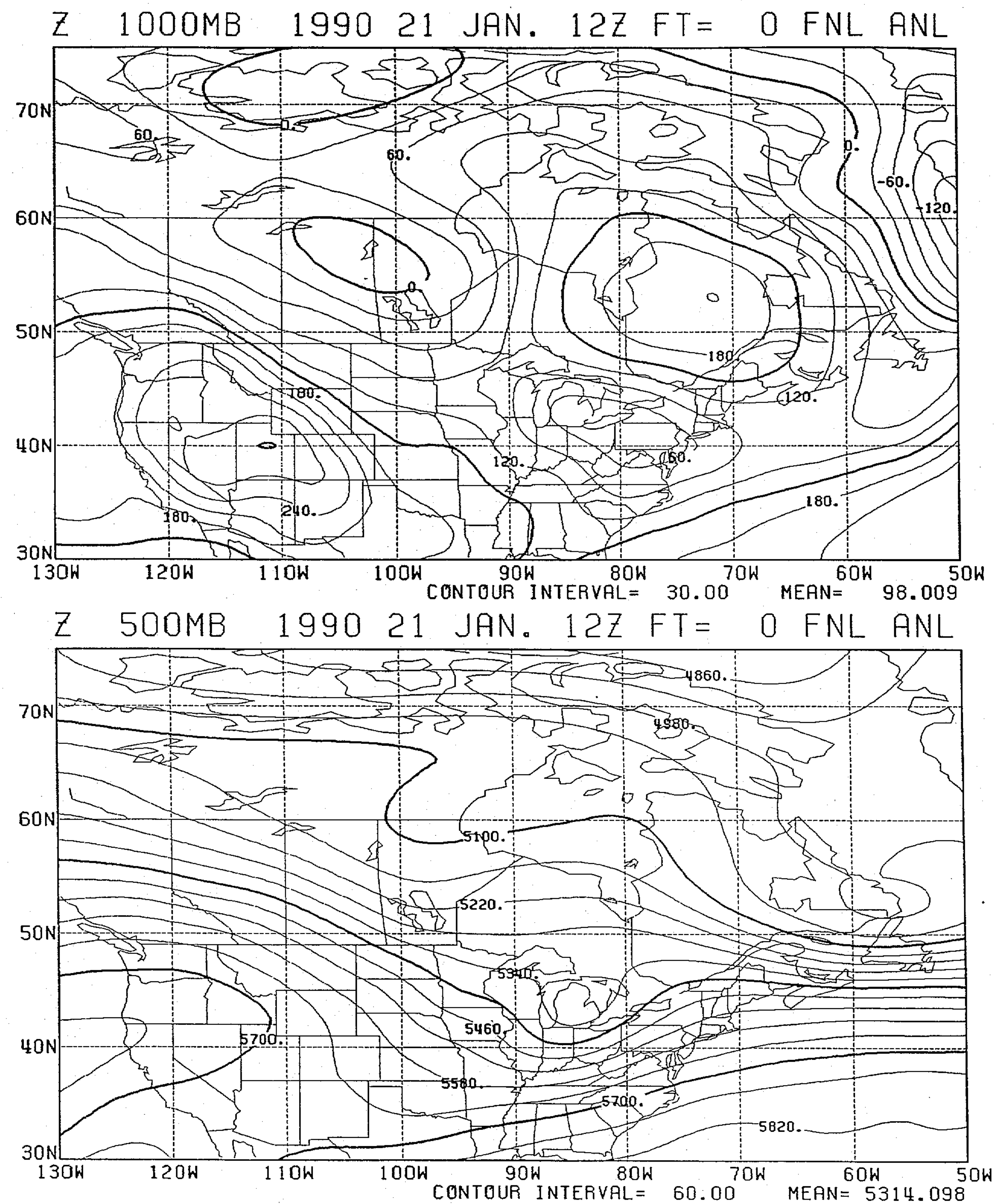


Fig. 10. NMC final analysis heights, 1200 GMT 21 January, 1990: (a) 1000 mb, (b) 500 mb.

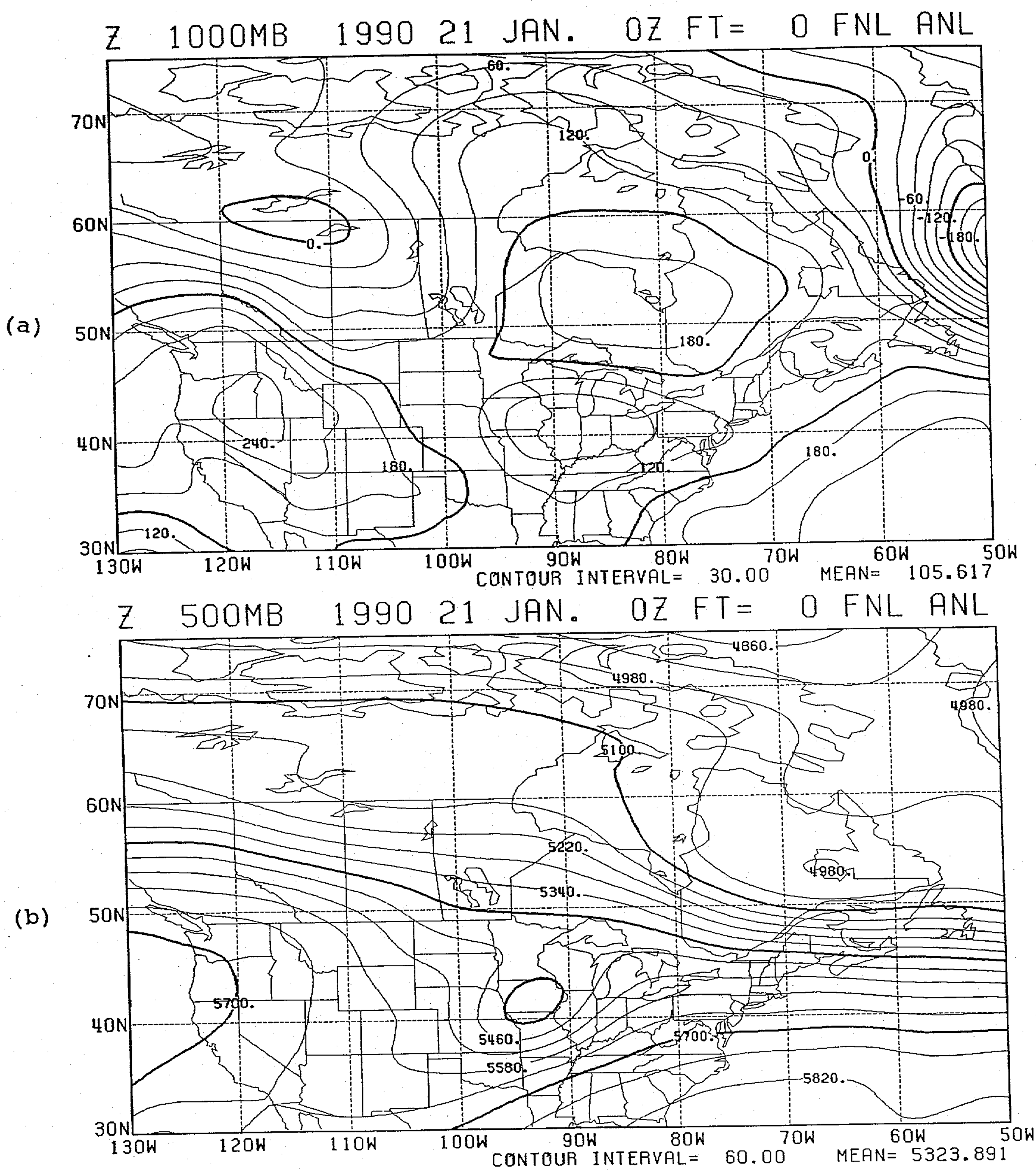
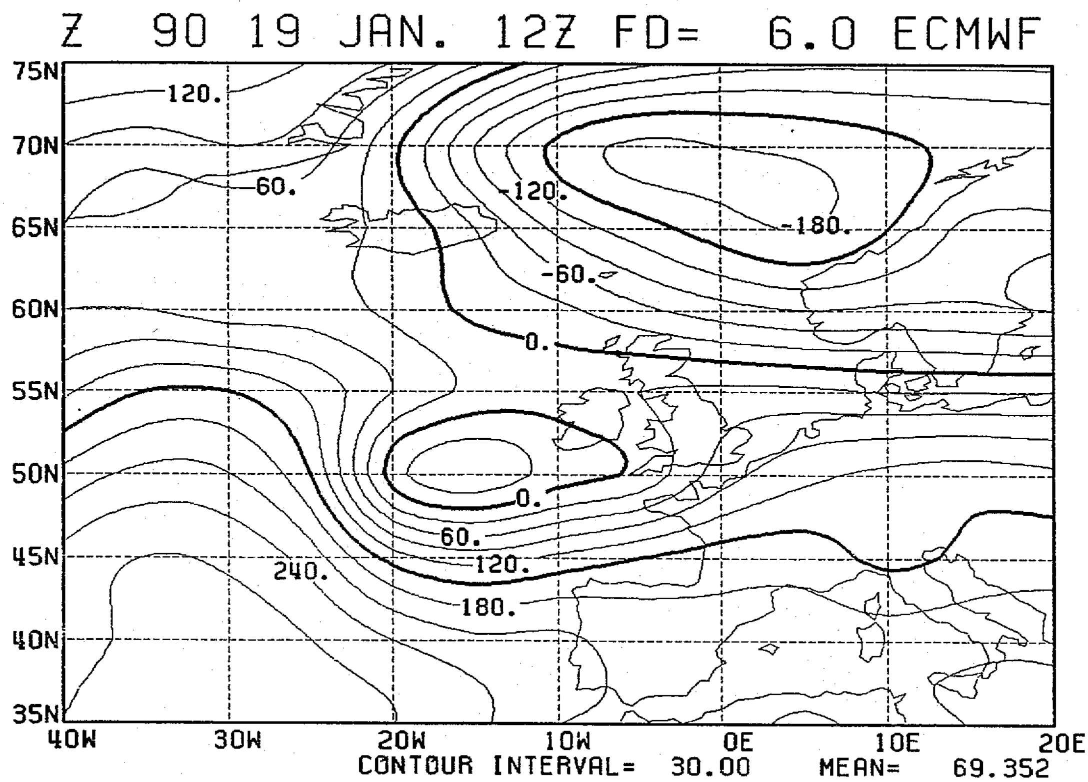


Fig. 11. NMC final analysis heights, 0000 GMT 21 January, 1990: (a) 1000 mb, (b) 500 mb.

(a)



(b)

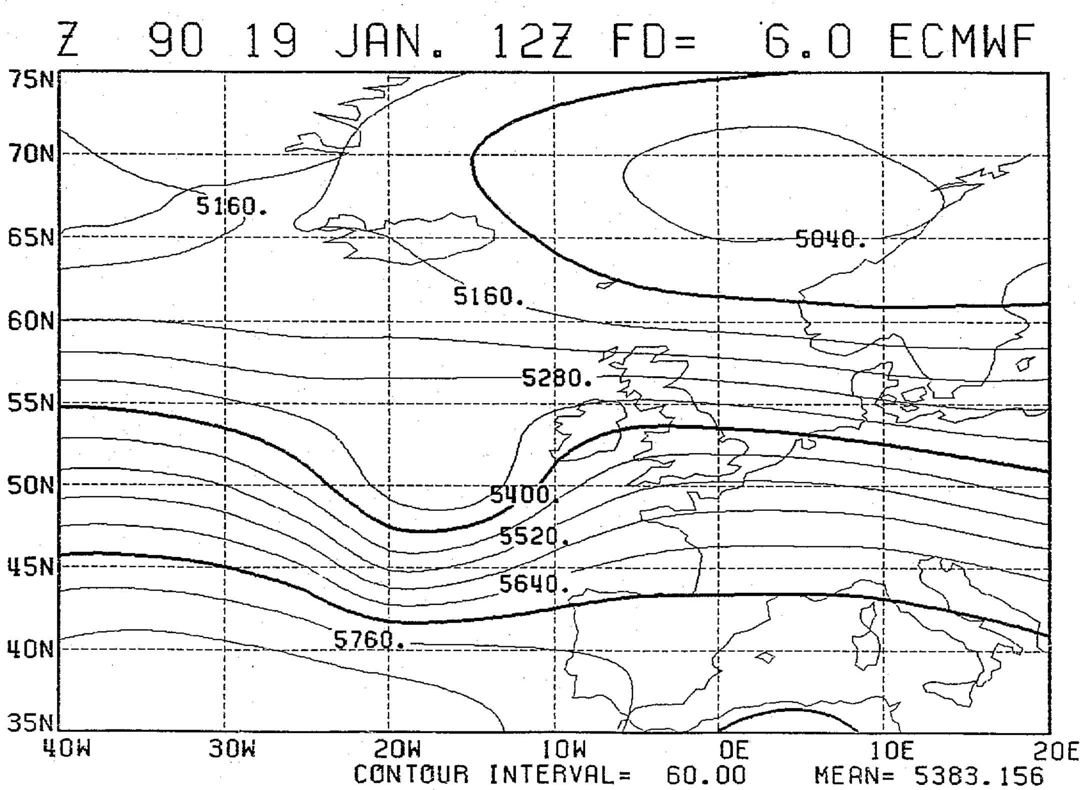


Fig. 12. European Centre 6 day height forecasts valid 1200 GMT 25 January, 1990: (a) 1000 mb, (b) 500 mb.

(a)

(b)

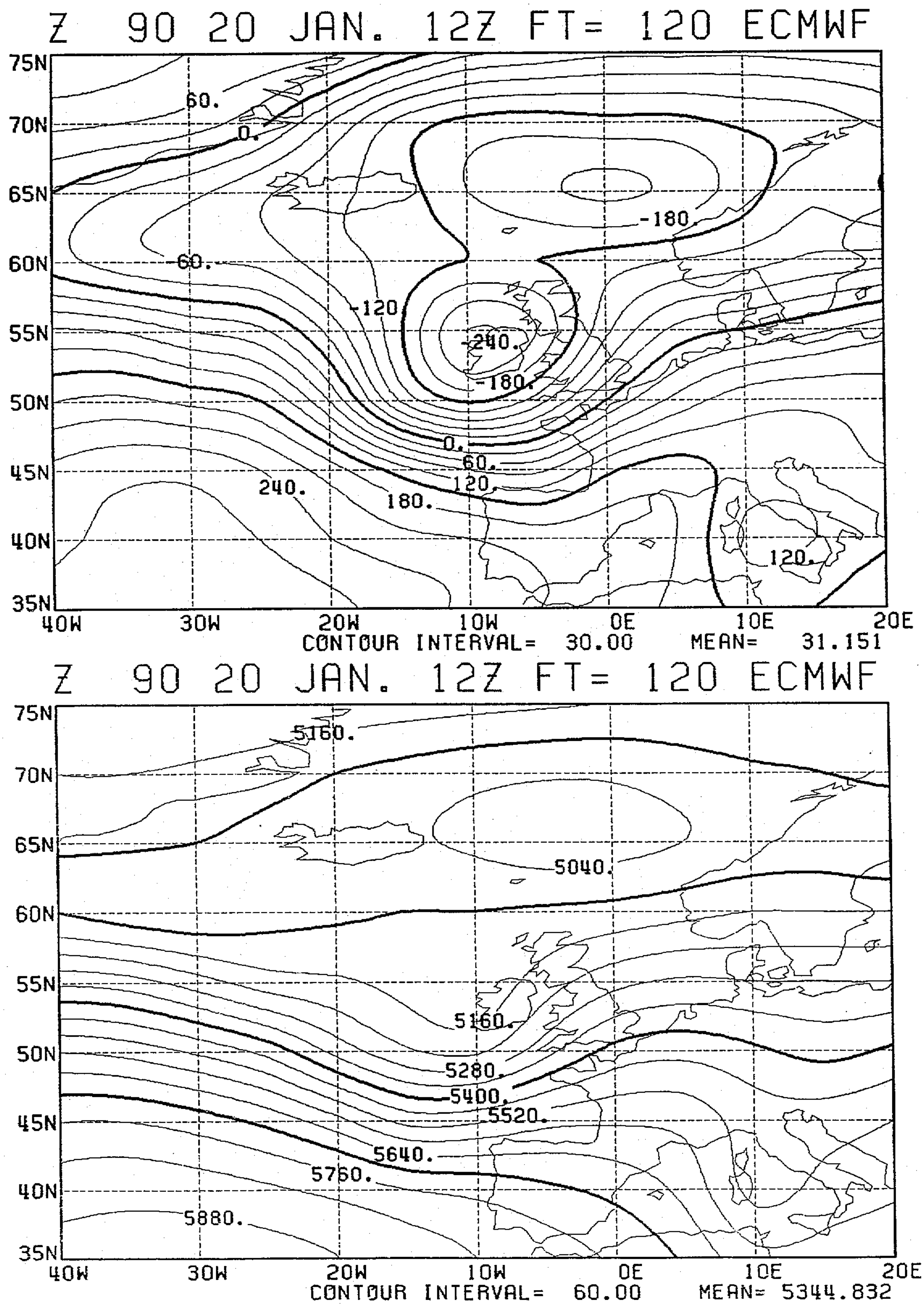


Fig. 13. European Centre 5 day height forecasts valid 1200 GMT 25 January, 1990: (a) 1000 mb, (b) 500 mb.

(a)

(b)

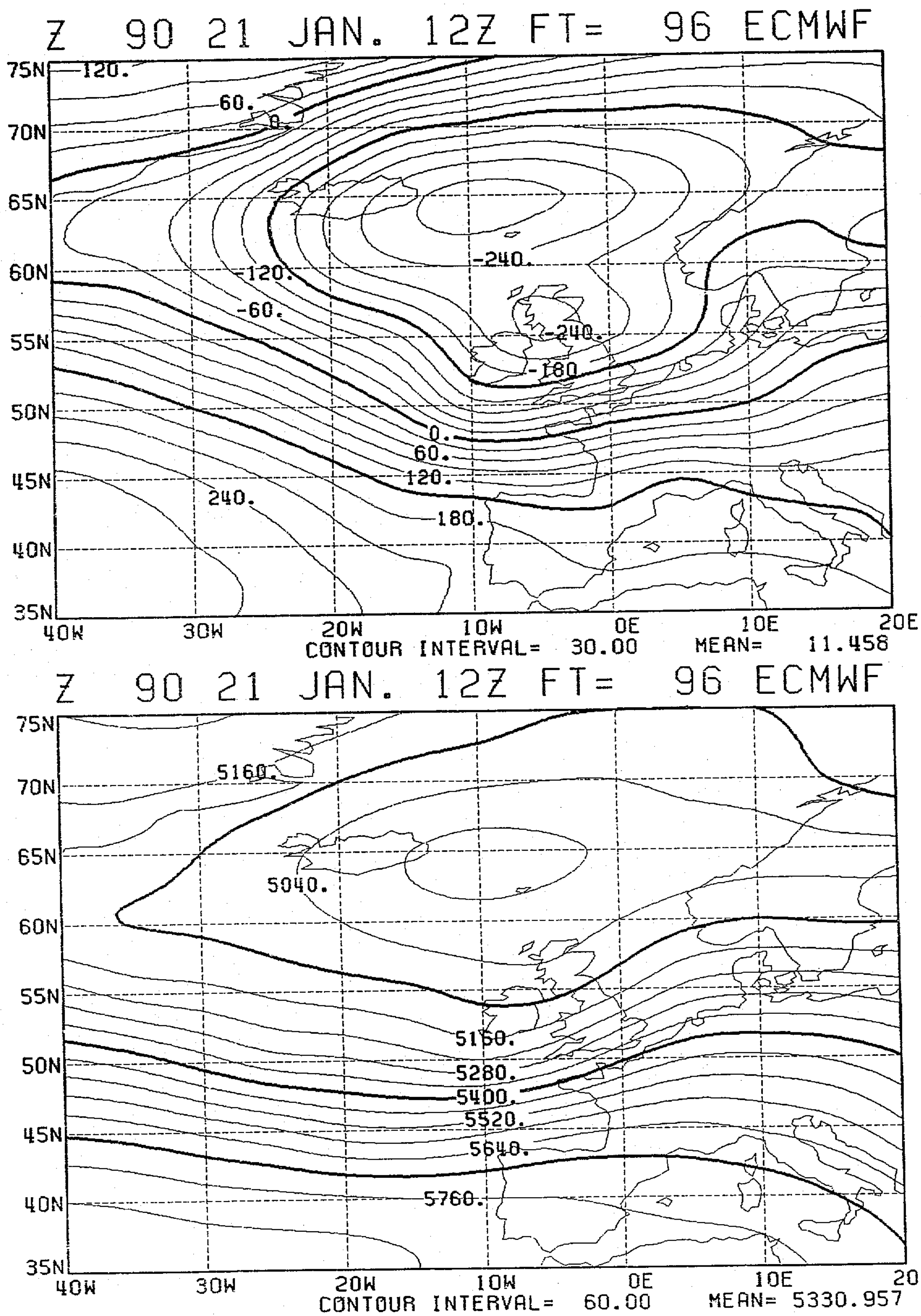


Fig. 14. European Centre 4 day height forecasts valid 1200 GMT 25 January, 1990: (a) 1000 mb, (b) 500 mb.

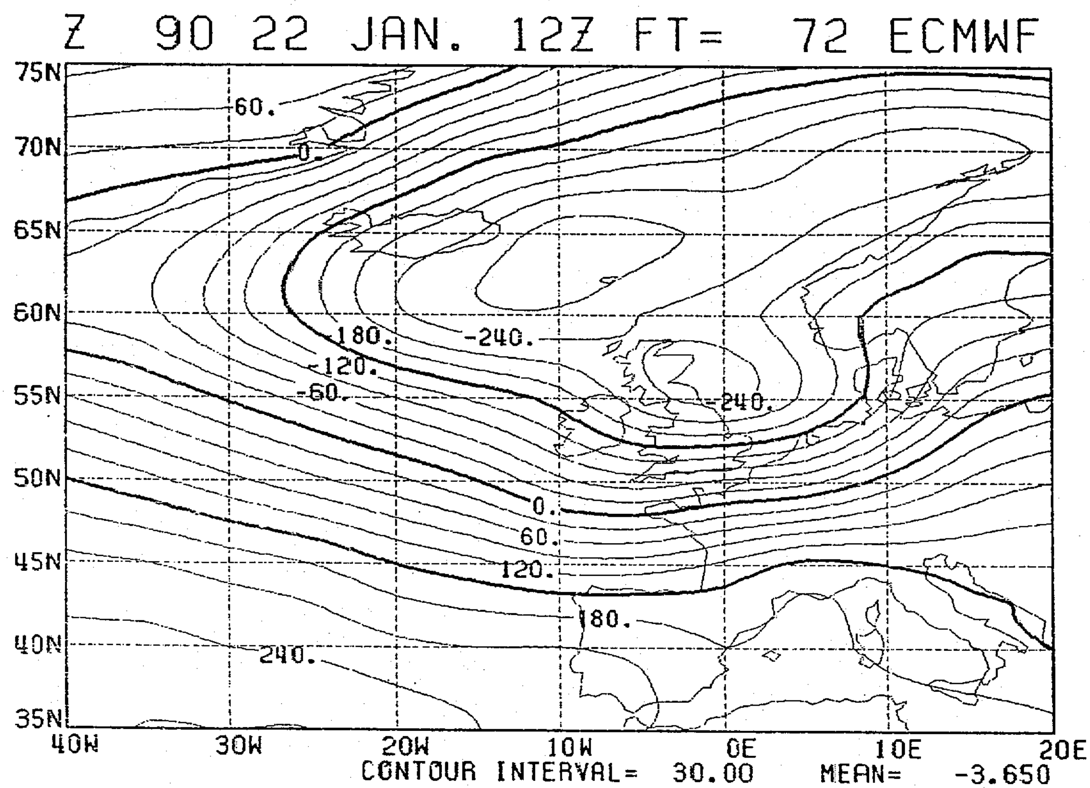


Fig. 15. European Centre 3 day 1000 mb height forecast valid 1200 GMT 25 January, 1990.

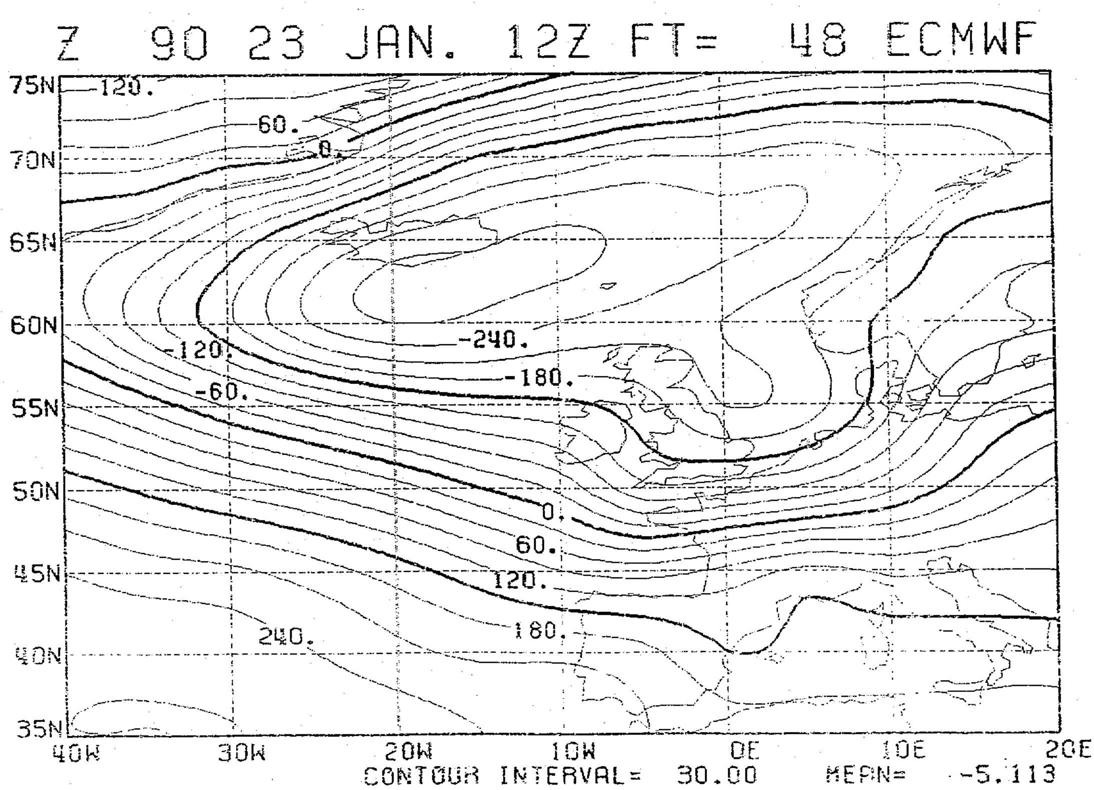


Fig. 16. European Centre 2 day 1000 mb height forecast valid 1200 GMT 25 January, 1990.

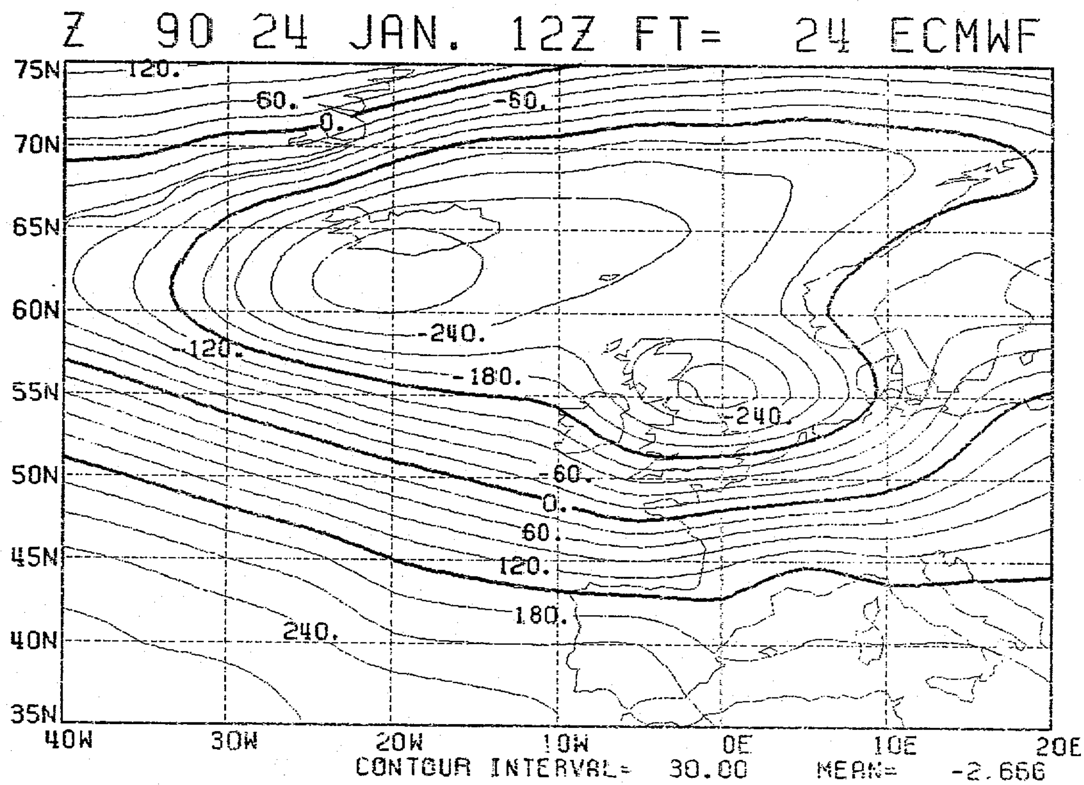


Fig. 17. European Centre 1 day 1000 mb height forecast valid 1200 GMT 25 January, 1990.

(a)

(b)

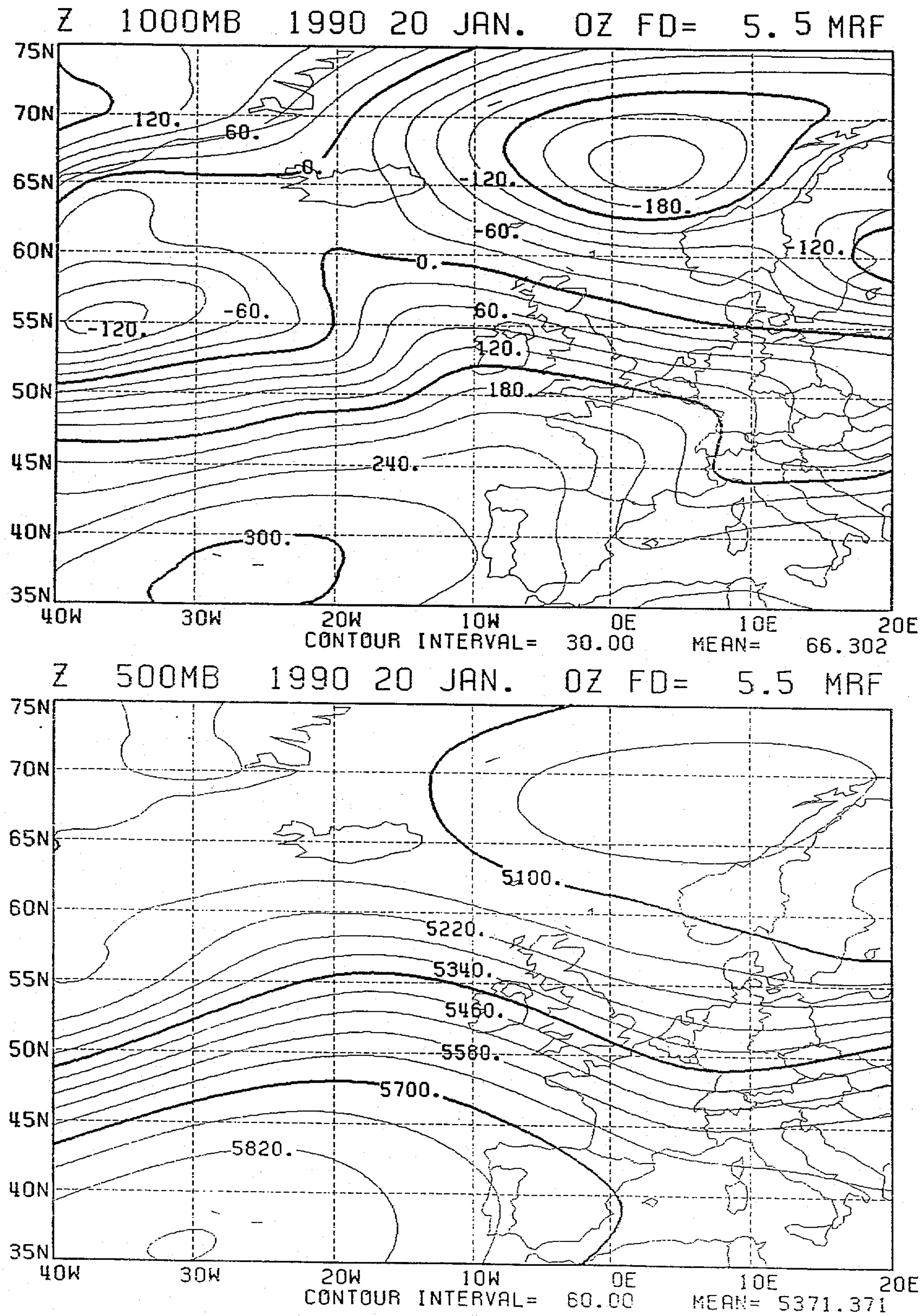


Fig. 18. NMC 5½ day height forecasts valid 1200 GMT 25 Janauary, 1990: (a) 1000 mb, (b) 500 mb.

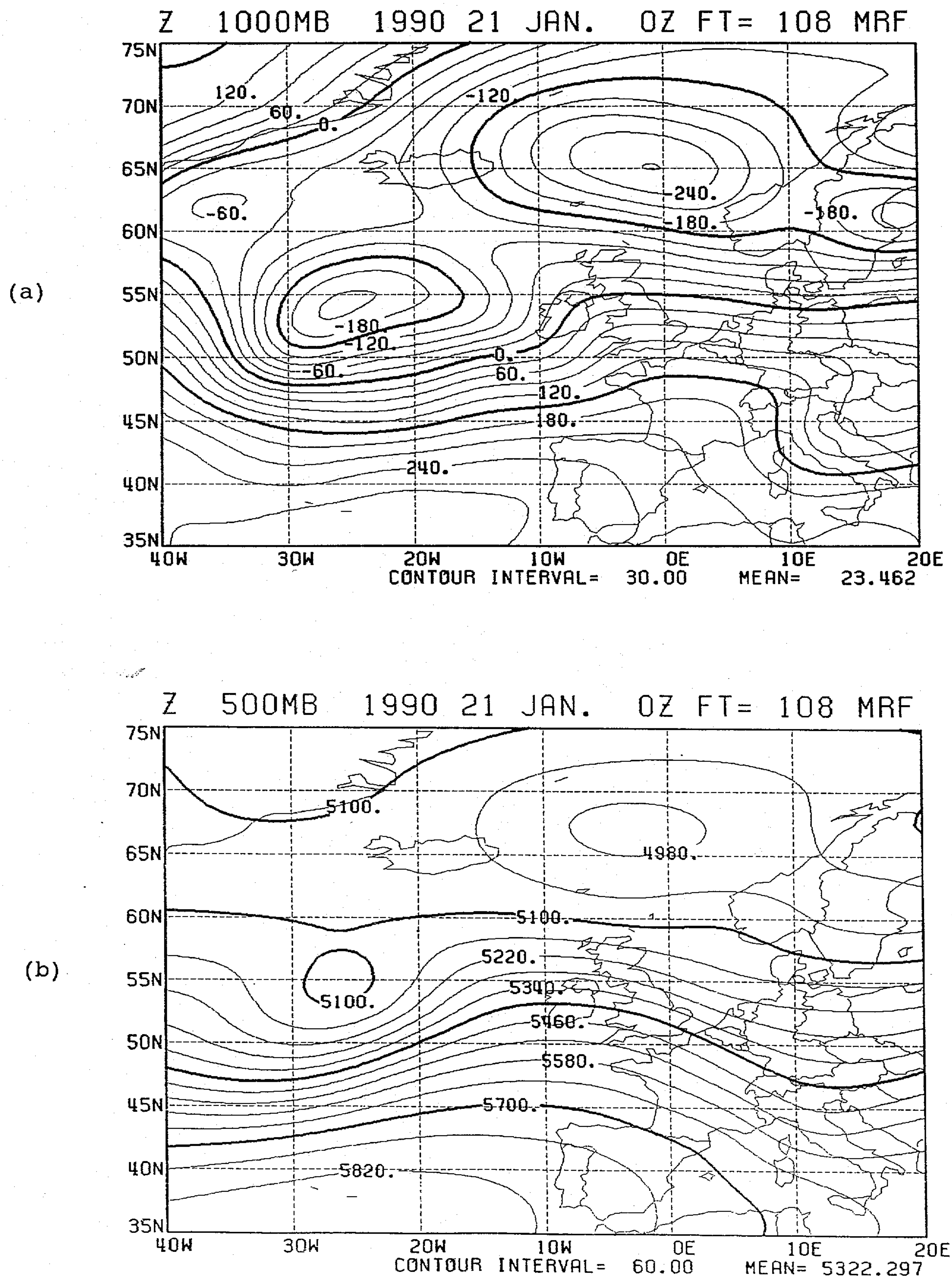
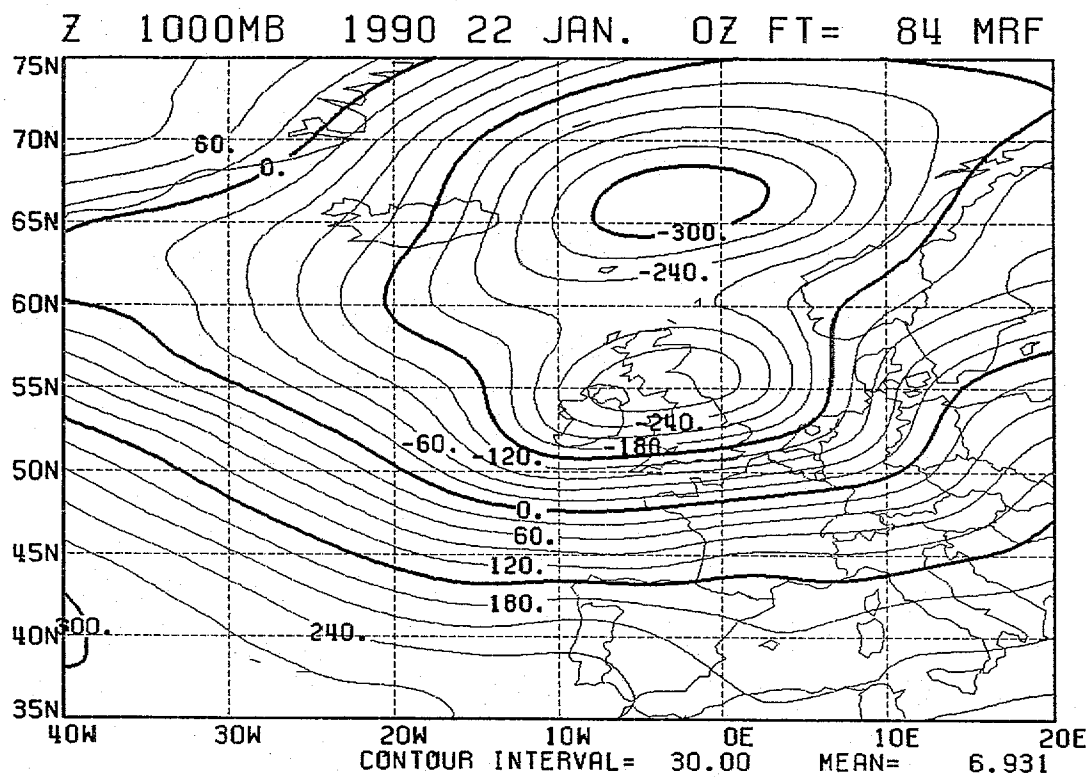


Fig. 19. NMC 4½ day height forecasts valid 1200 GMT 25 January, 1990: (a) 1000 mb, (b) 500 mb.

(a)



(b)

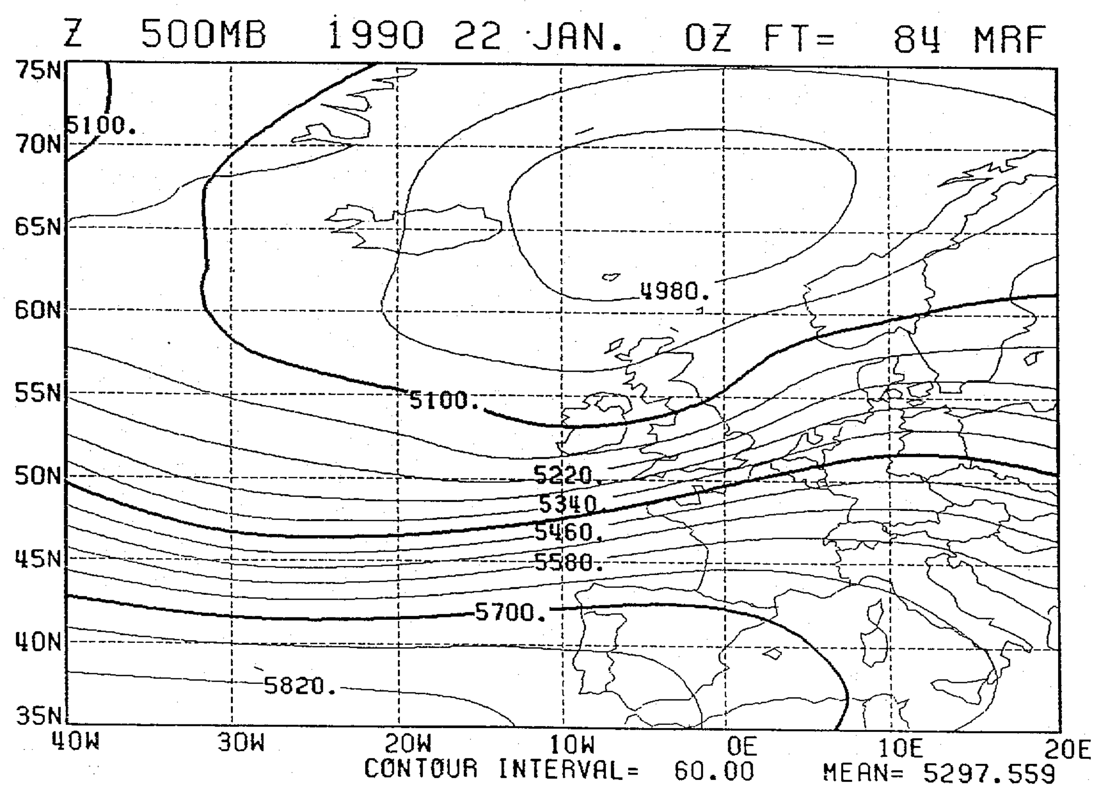


Fig. 20. NMC 3½ day height forecast valid 1200 GMT 25 January, 1990: (a) 1000 mb, (b) 500 mb.

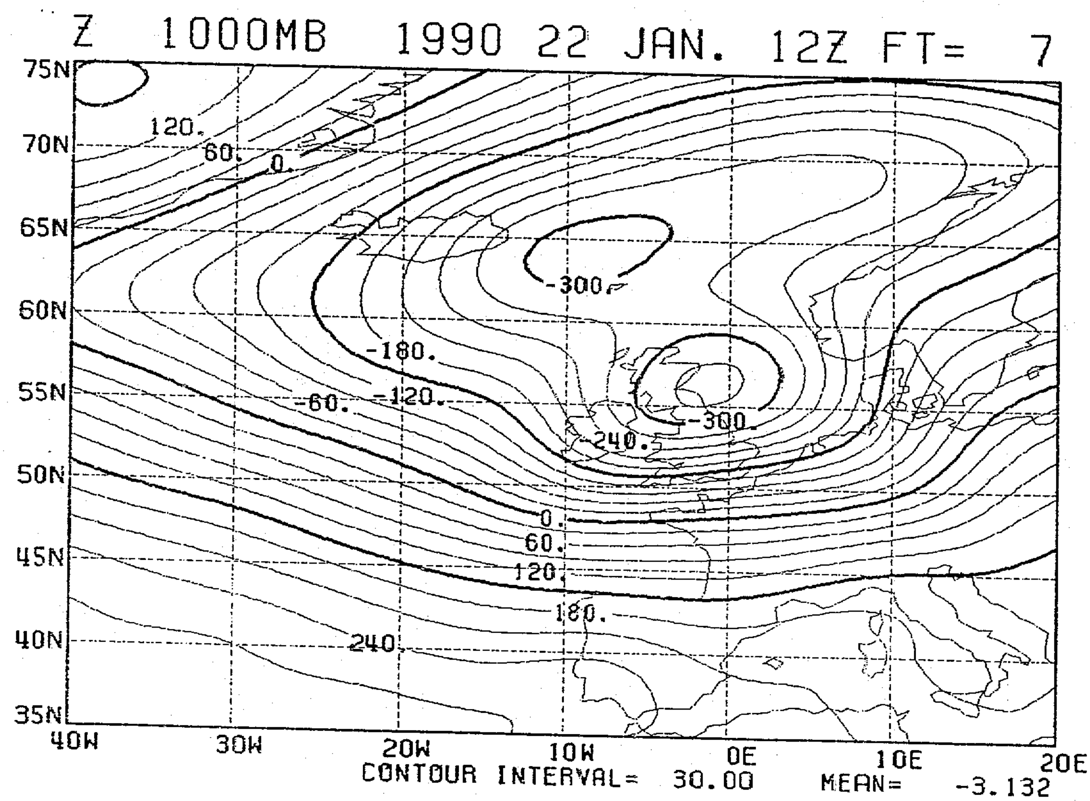


Fig. 21. NMC 3 day 1000 mb forecast heights valid 1200 GMT 25 January, 1990.

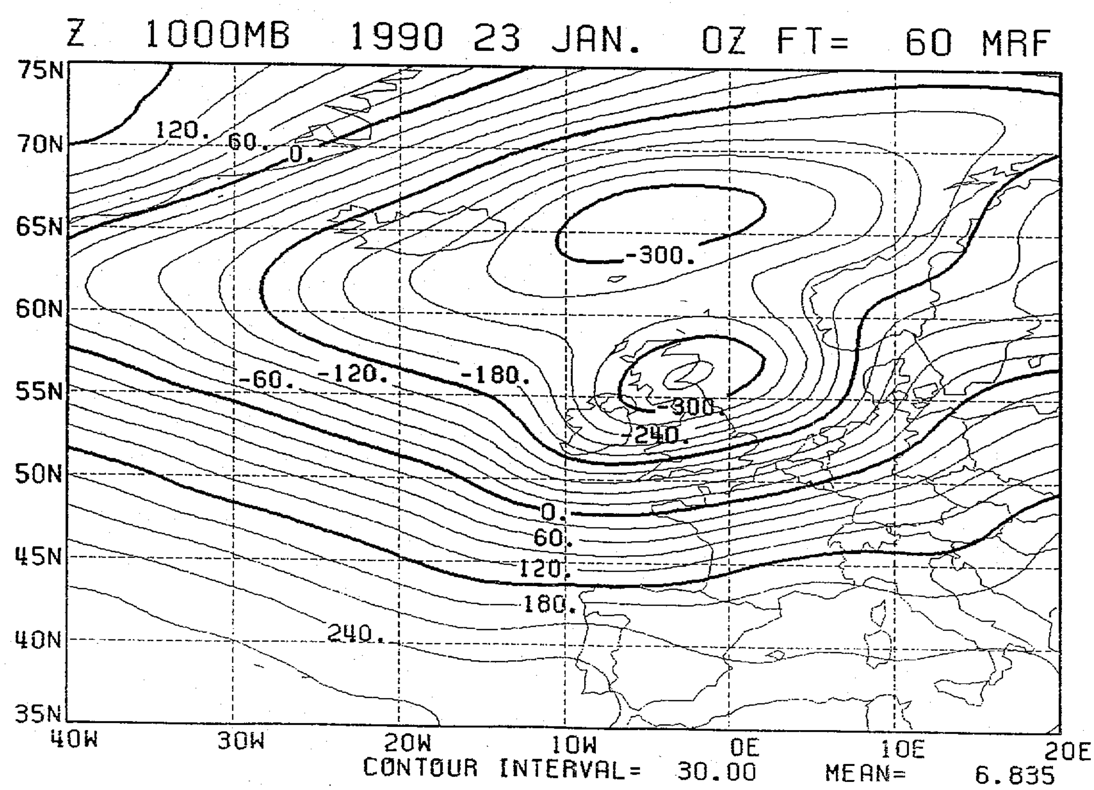


Fig. 22. NMC $2\frac{1}{2}$ day 1000 mb forecast heights valid 1200 GMT 25 January, 1990.

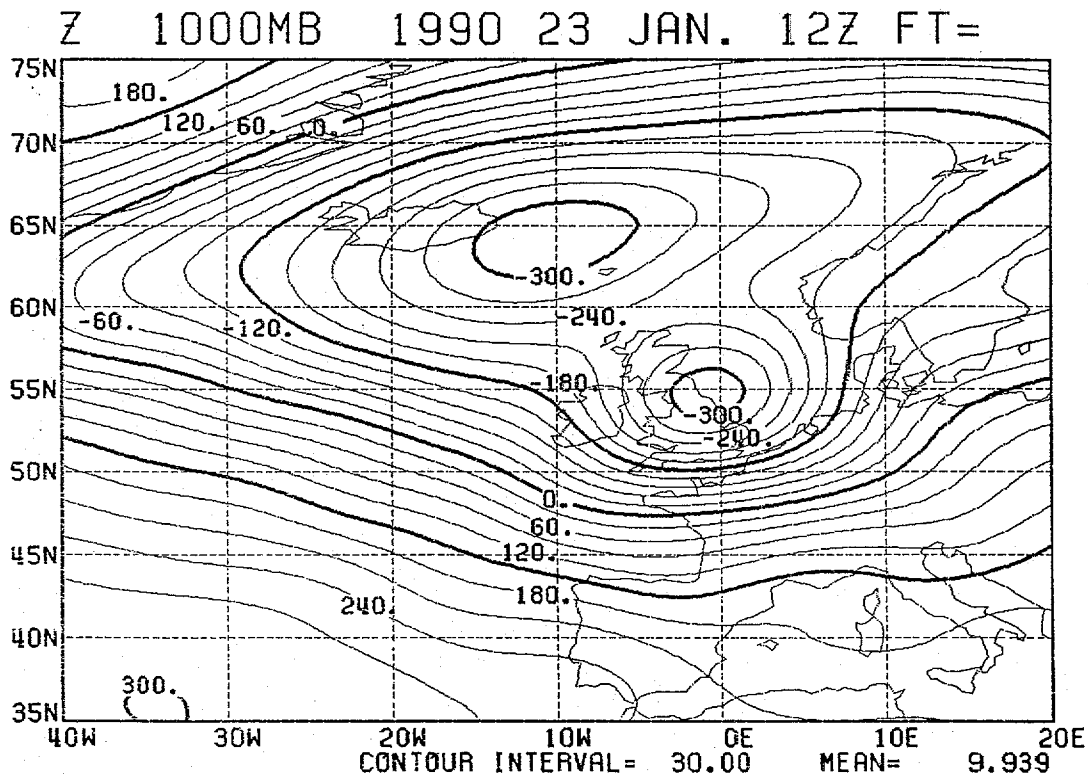


Fig. 23. NMC 2 day 1000 mb forecast heights valid 1200 GMT 25 January, 1990.

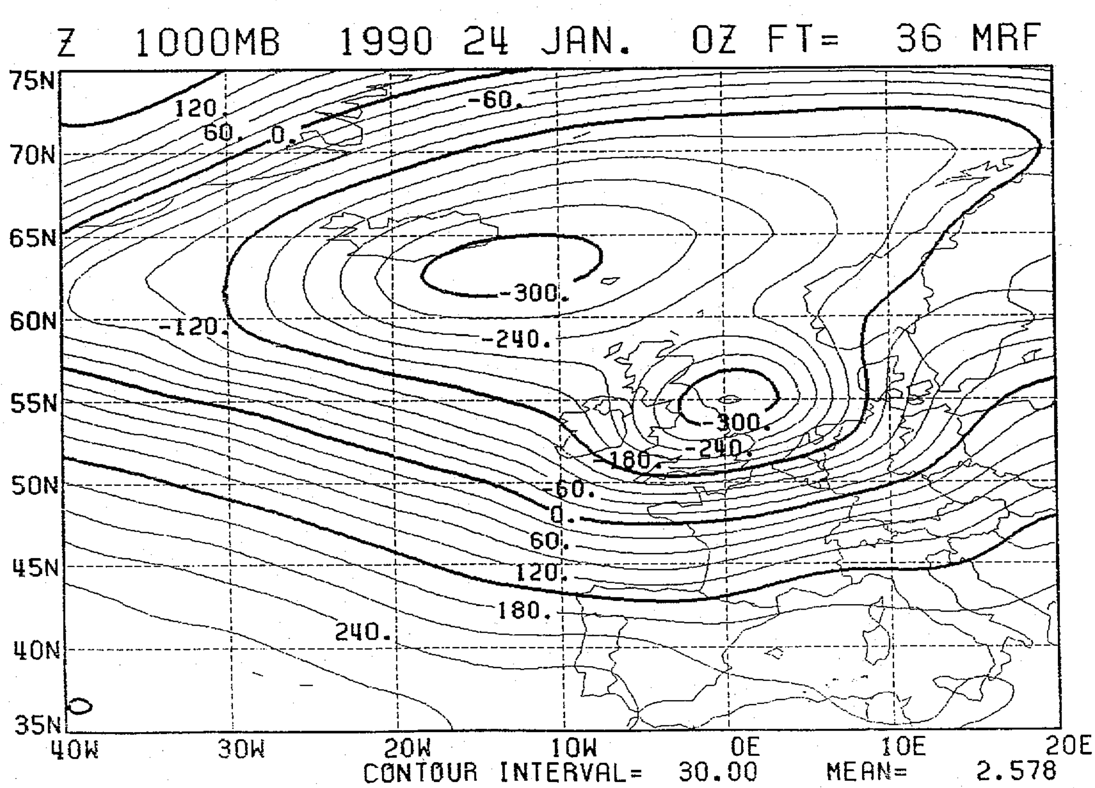


Fig. 24. NMC $1\frac{1}{2}$ day 1000 mb forecast heights valid 1200 GMT 25 Janauary, 1900.

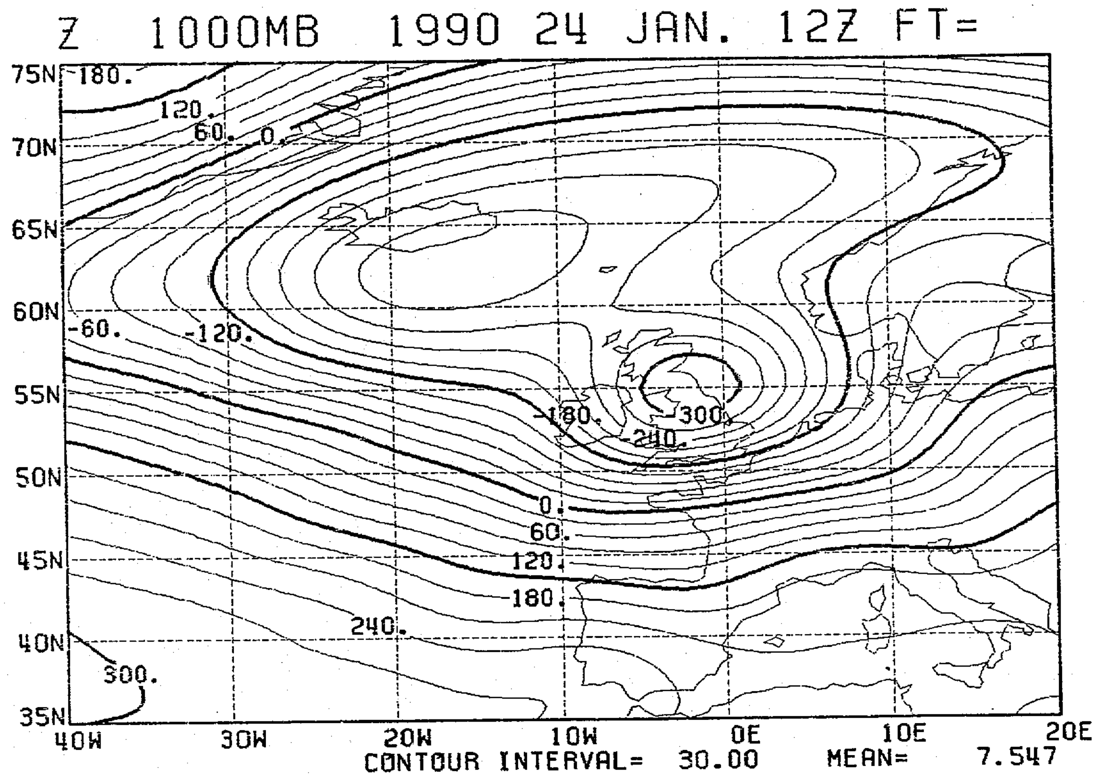


Fig. 25. NMC 1 day 1000 mb forecast heights valid 1200 GMT 25 January, 1990.

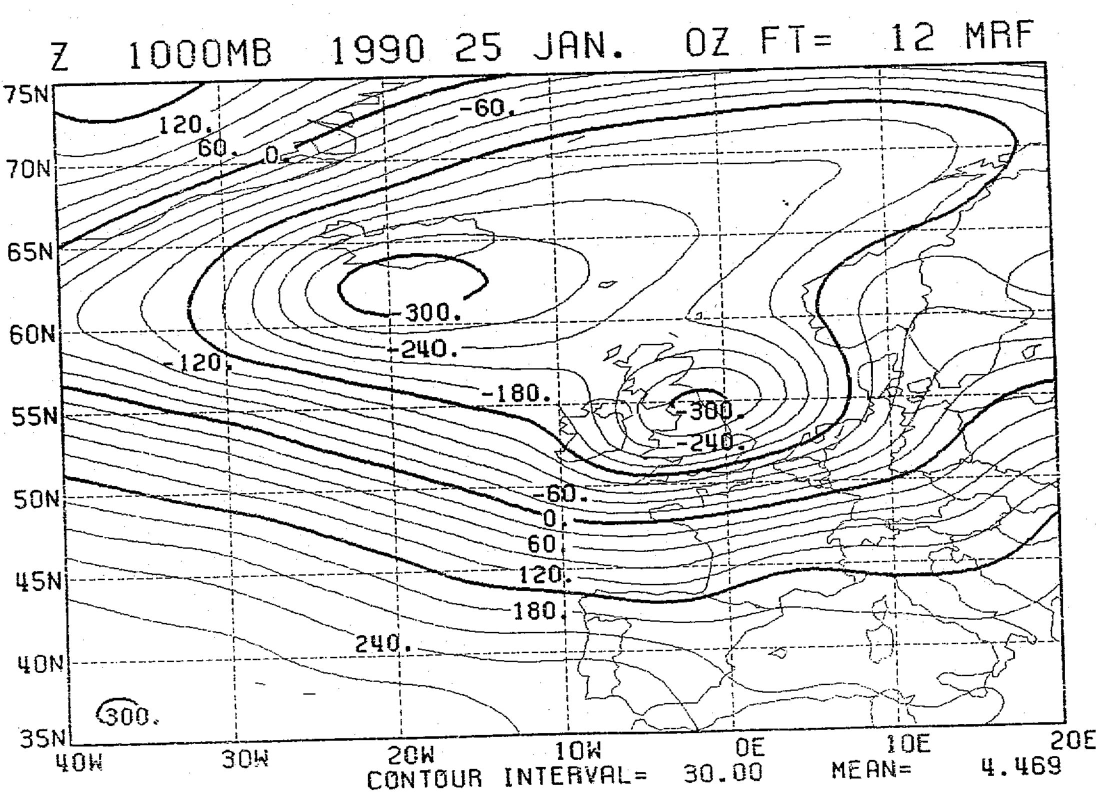


Fig. 26. NMC ½ day 1000 mb forecast heights valid 1200 GMT 25 January, 1990.

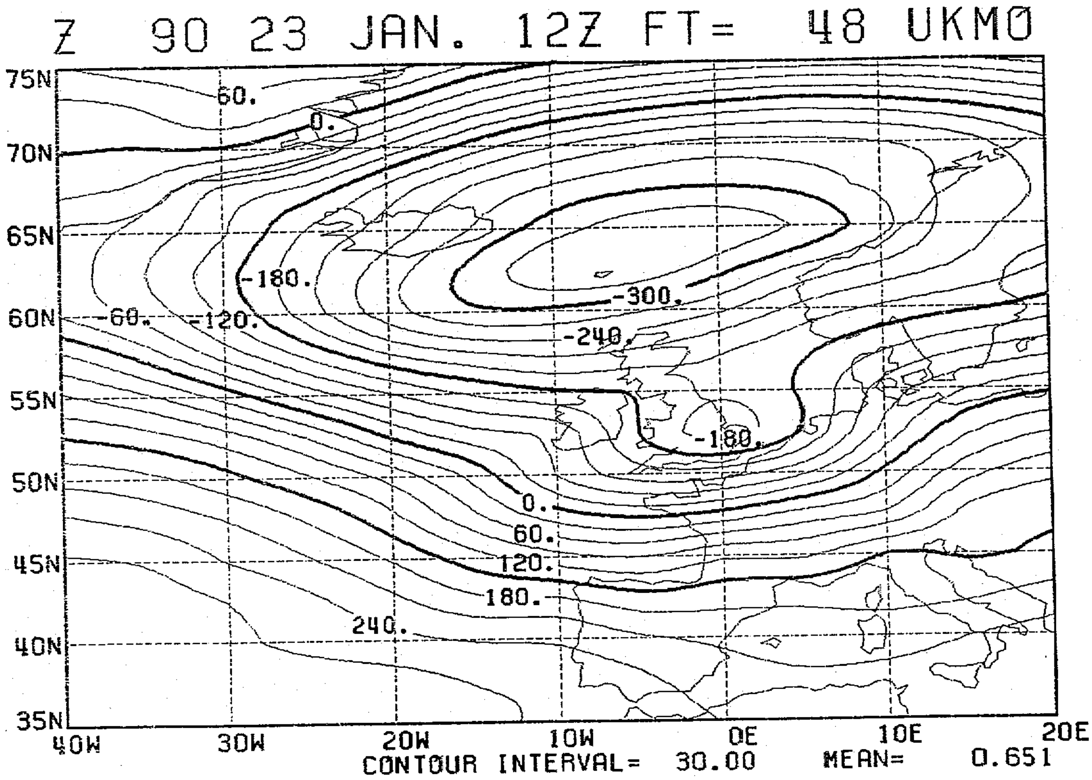


Fig. 27. British 2 day forecast 1000 mb heights valid 1200 GMT 25 January, 1990.

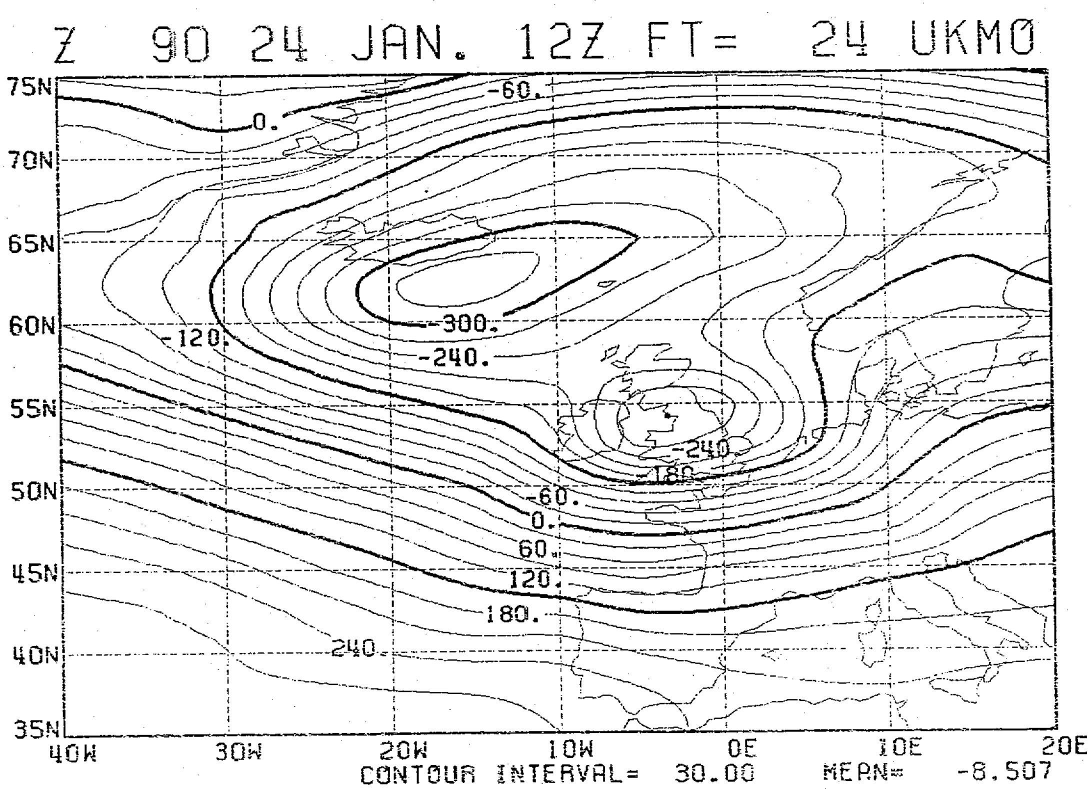
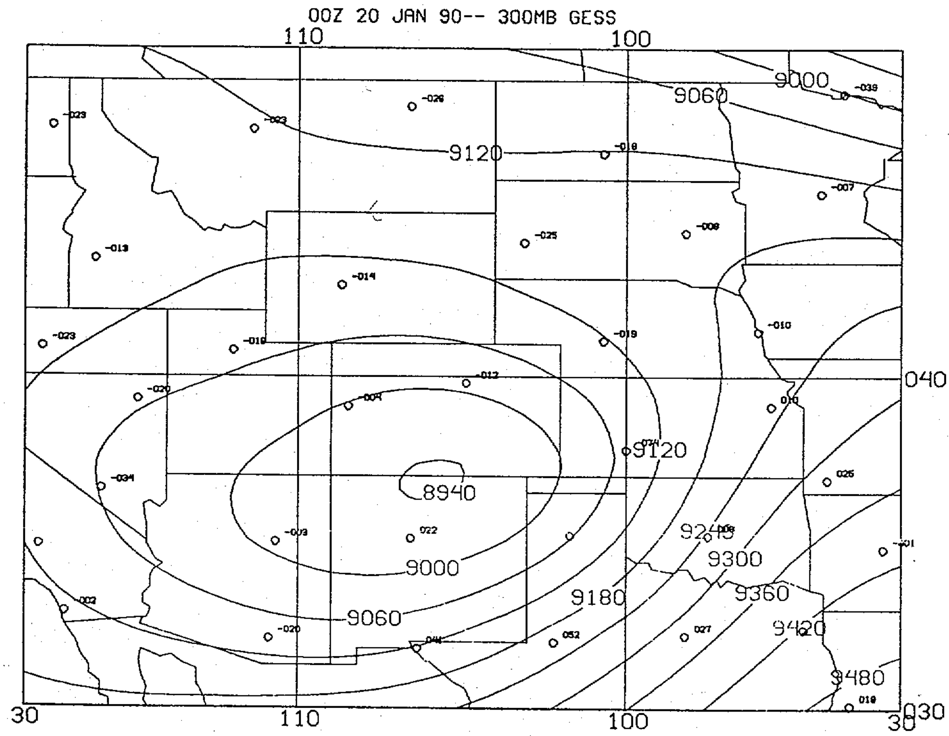


Fig. 28. British 1 day forecast 1000 mb Heights valid 1200 GMT 25 January, 1900.

(a)



(b)

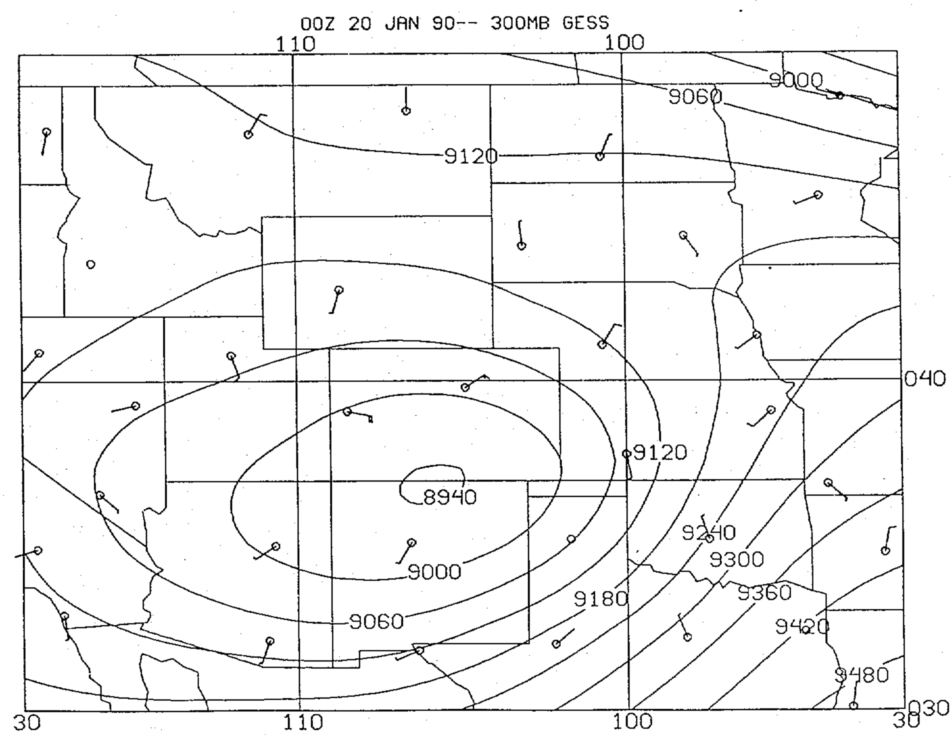
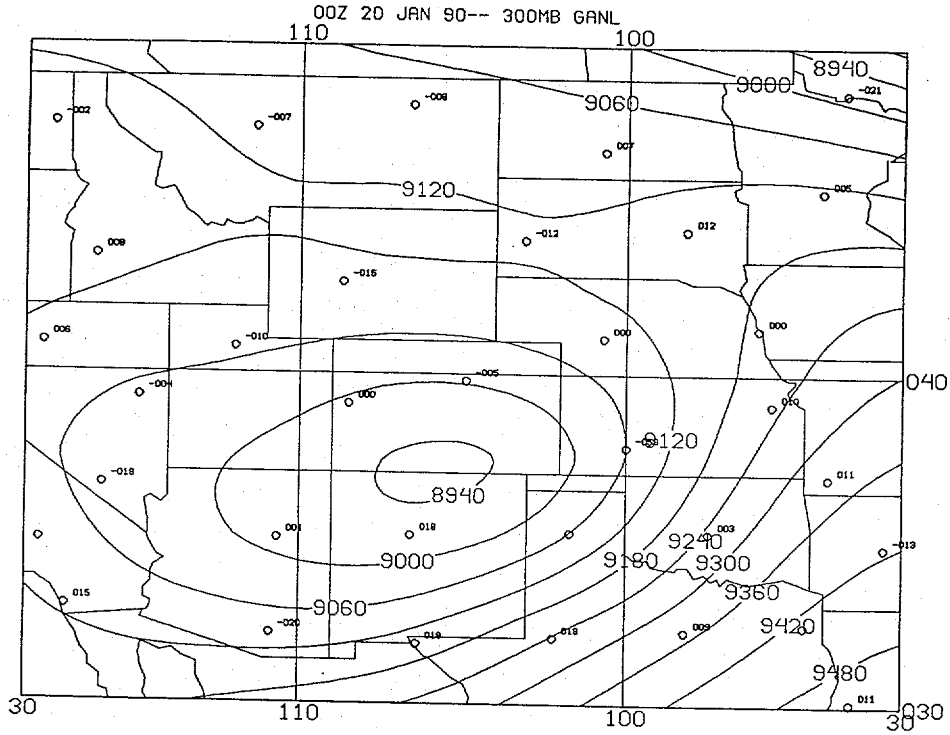


Fig. 29. NMC first-guess 300 mb heights for 0000 GMT 20 January, 1990: (a) with heights residuals, (b) with wind residuals.

(a)



(b)

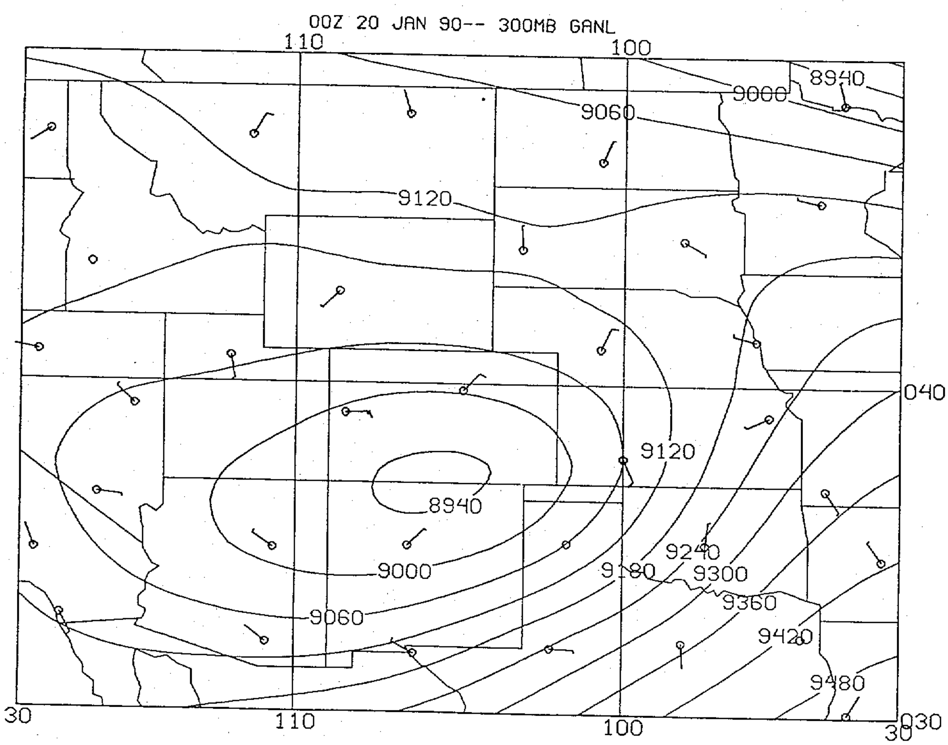
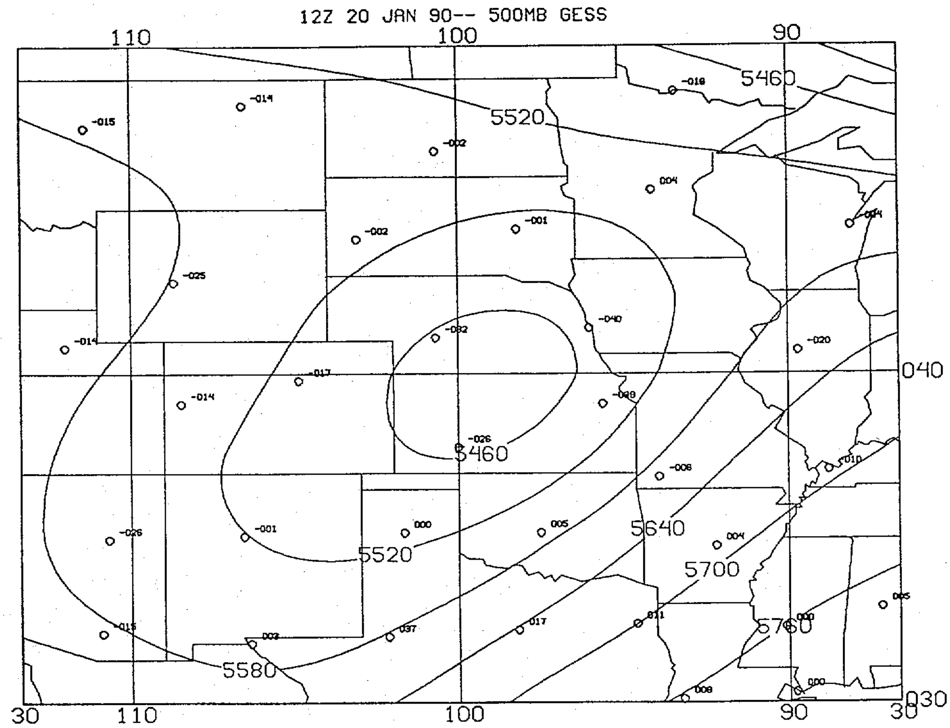


Fig. 30. NMC analysis 300 mb heights for 0000 GMT 20 January, 1990: (a) with height residuals, (b) with wind residuals.

(a)



(b)

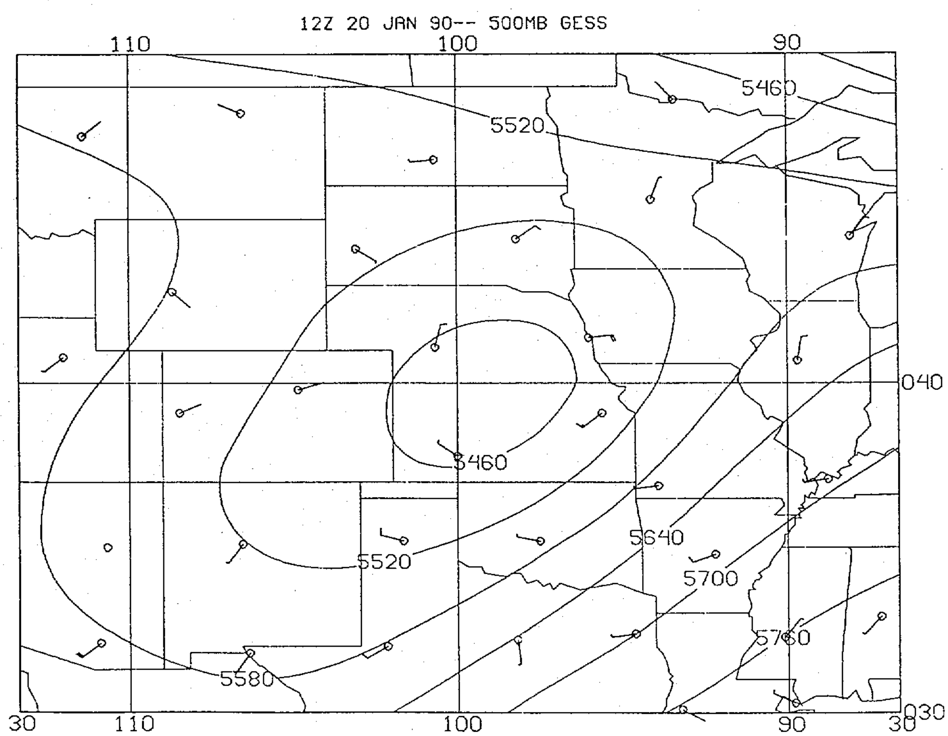
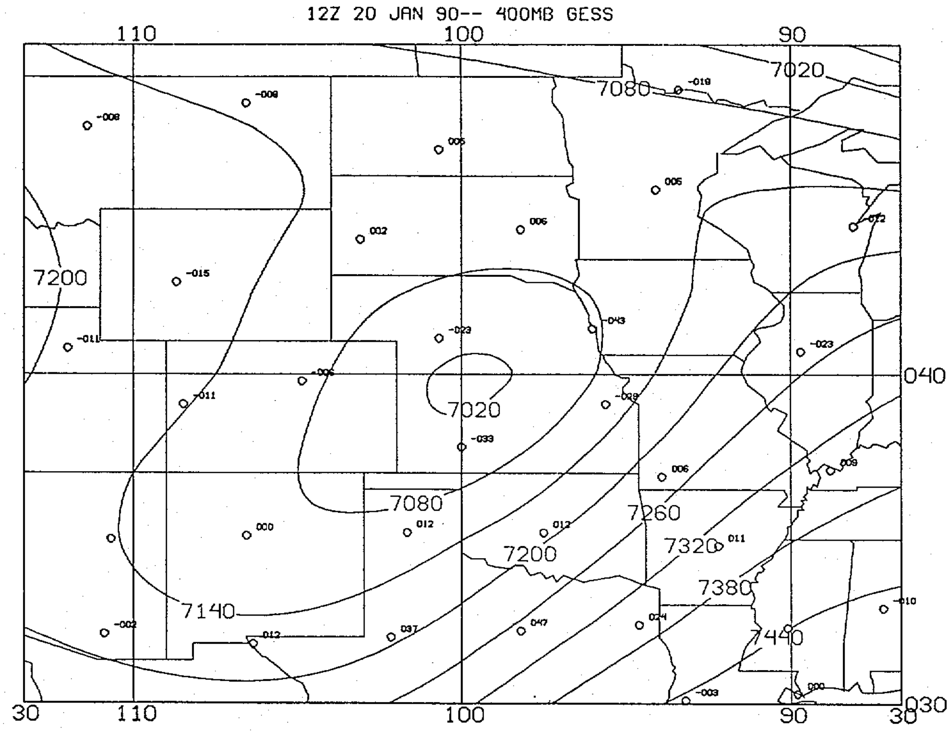


Fig. 31. NMC first-guess 500 mb heights for 1200 GMT 20 January, 1900: (a) with height residuals, (b) with wind residuals.

(a)



(b)

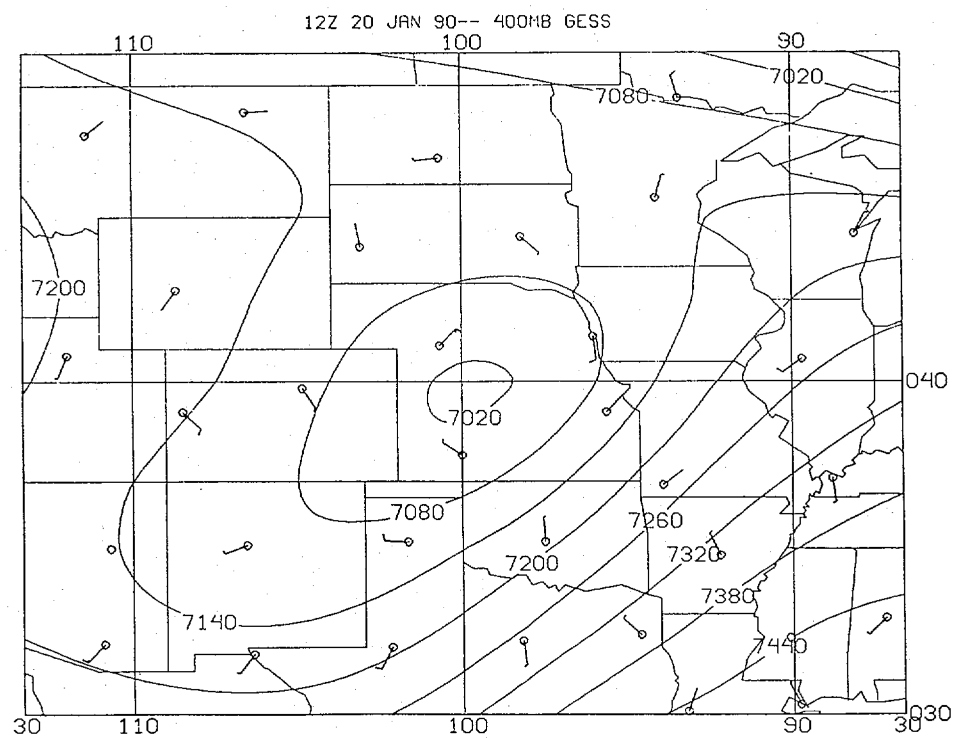
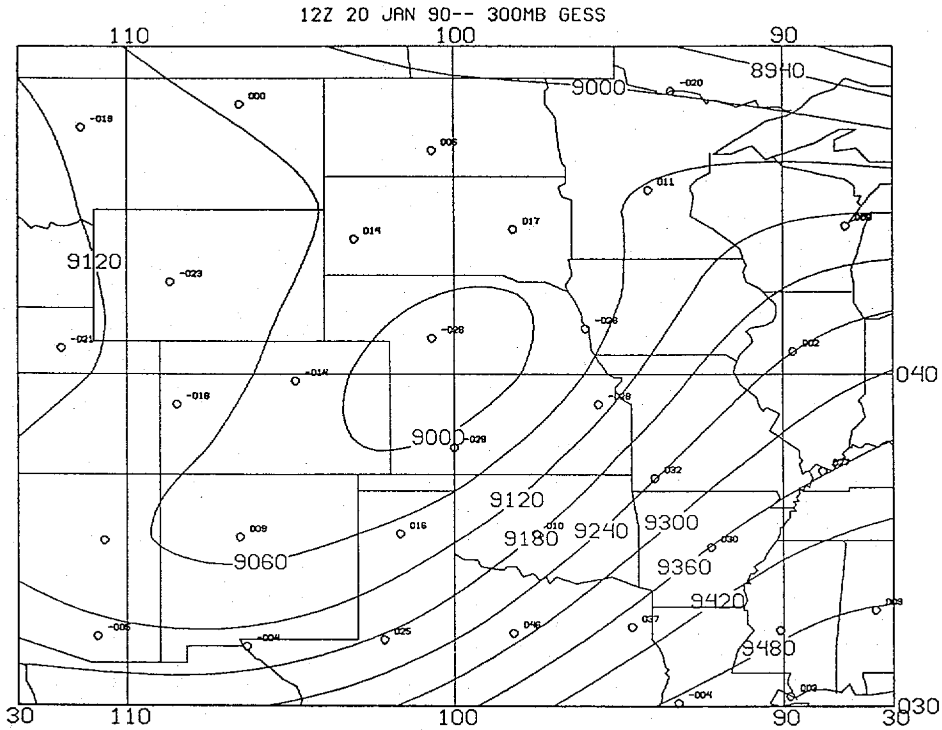


Fig. 32. NMC first-guess 400 mb heights for 1200 GMT 20 January, 1990: (a) with height residuals, (b) with wind residuals.

(a)



(b)

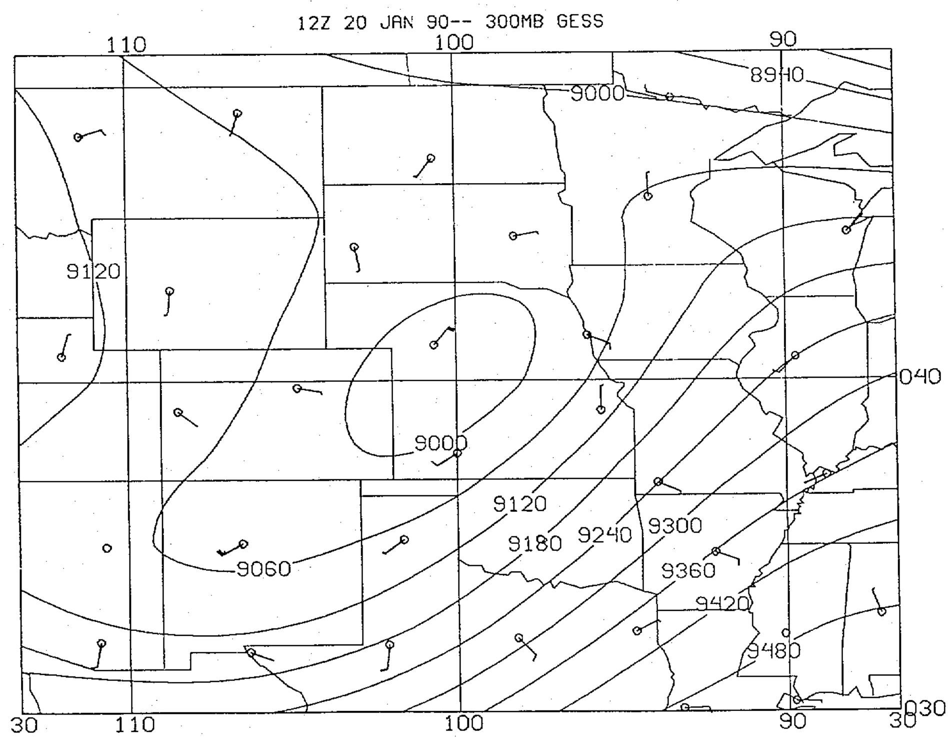
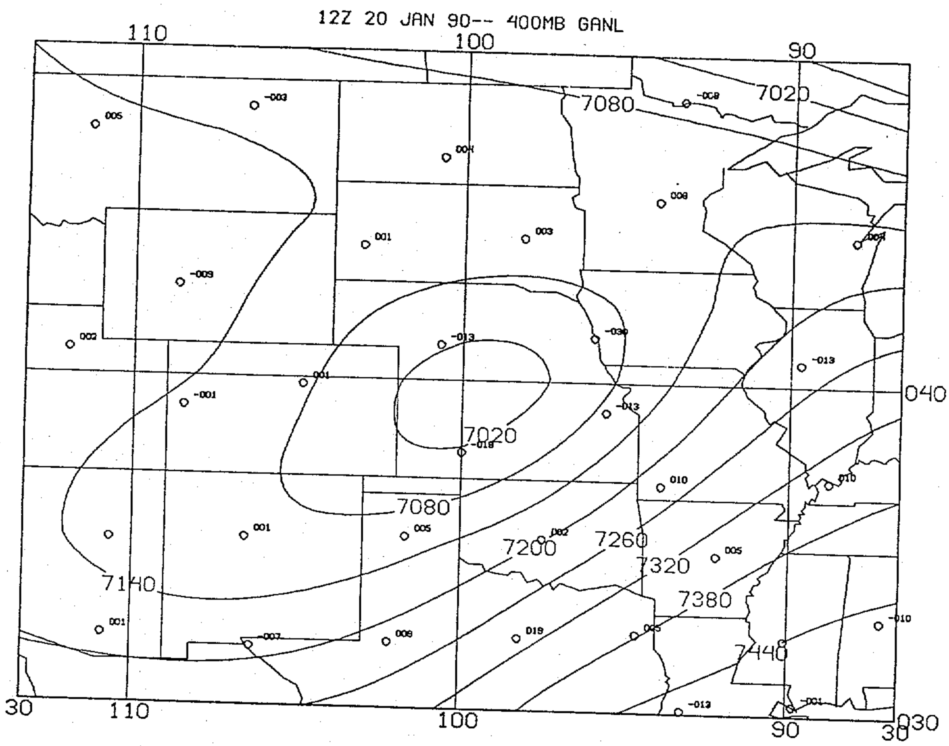


Fig. 33. NMC first-guess 300 mb heights for 1200 GMT 20 January, 1990: (a) with height residuals, (b) with wind residuals.

(a)



(b)

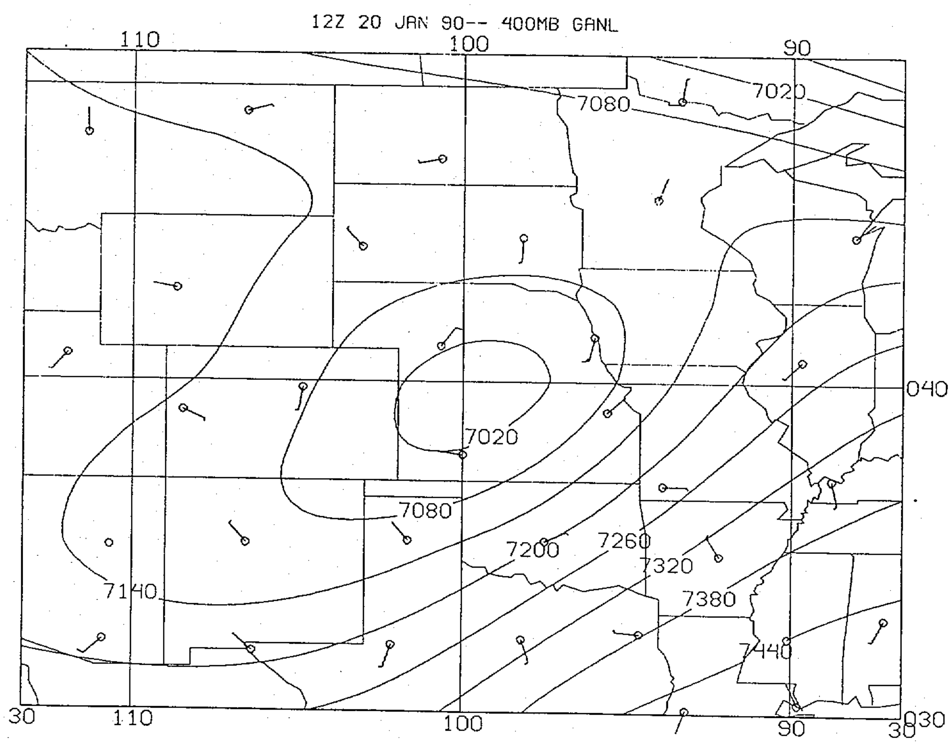
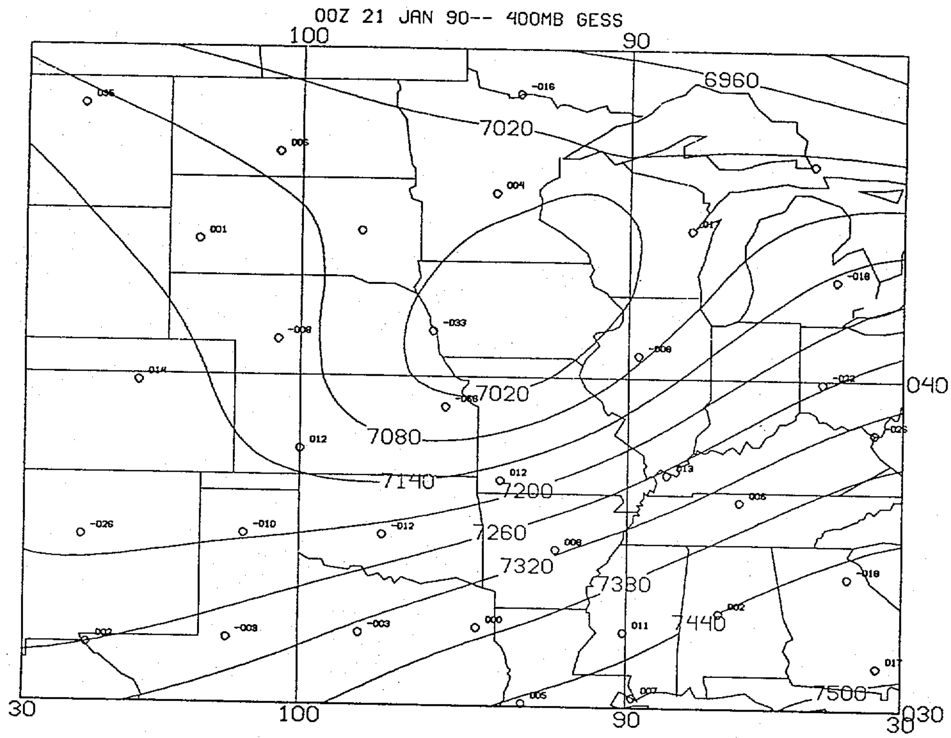


Fig. 34. NMC analysis 400 mb heights for 1200 GMT 20 January, 1990: (a) with height residuals, (b) with wind residuals.

(a)



(b)

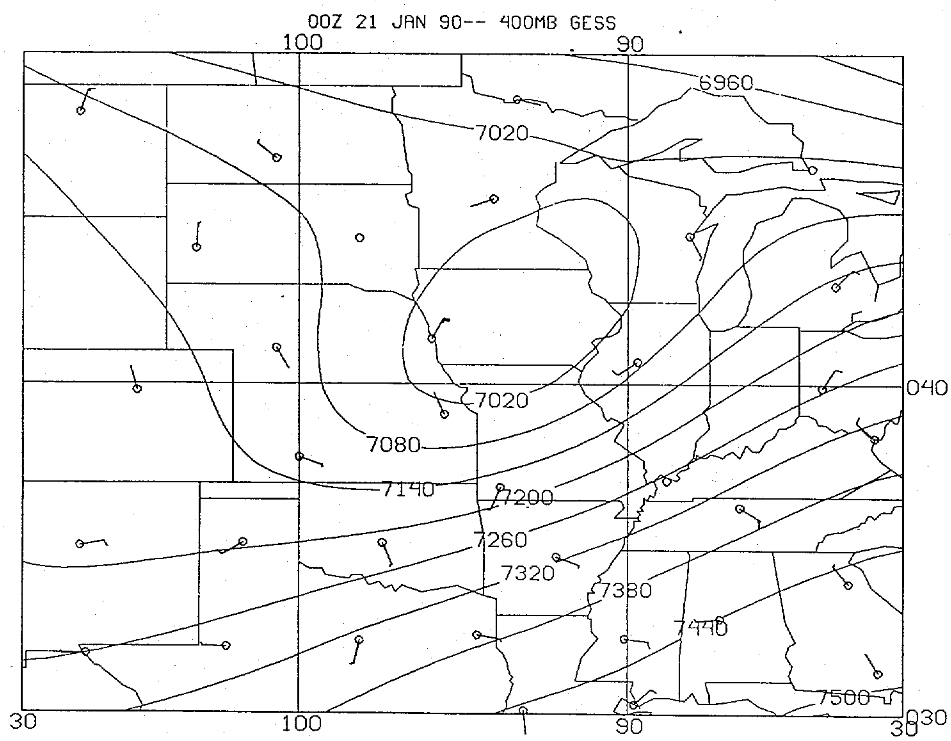
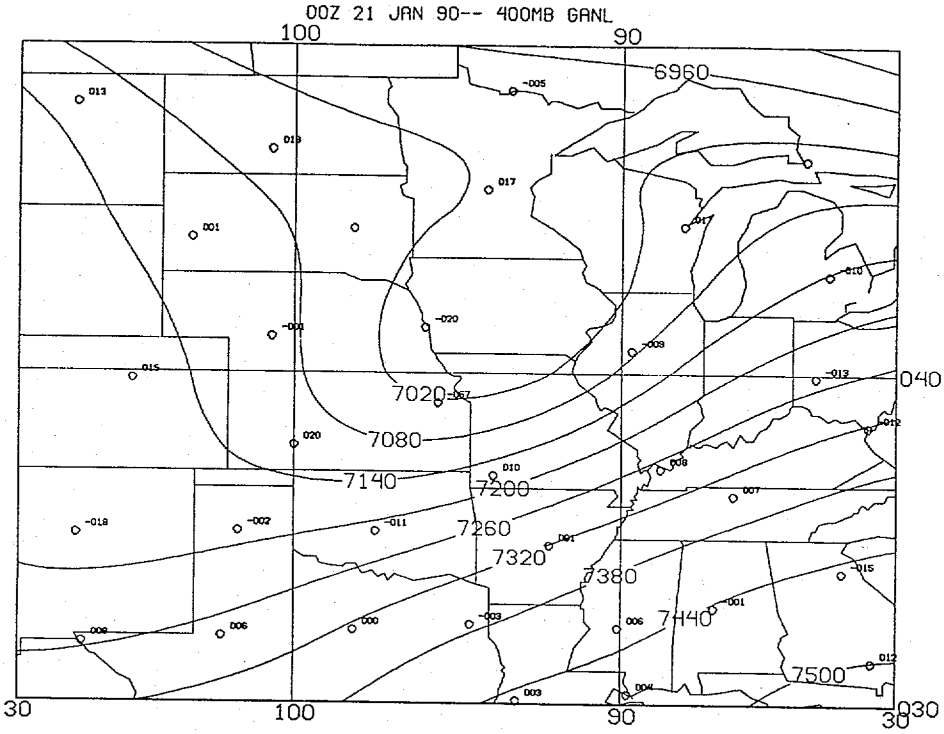


Fig. 35. NMC first-guess 400 mb heights for 1200 GMT 21 January, 1990: (a) with height residuals, (b) with wind residuals.

(a)



(b)

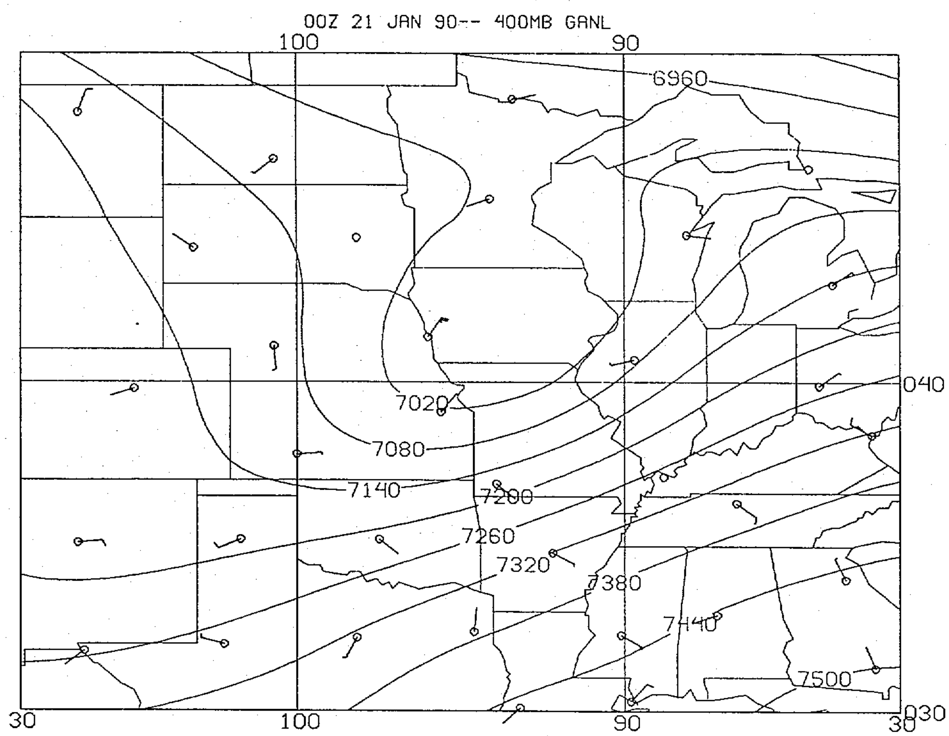


Fig. 36. NMC analysis 400 mb heights for 0000 GMT 21 January, 1990: (a) with height residuals, (b) with wind residuals.

(a)

(b)

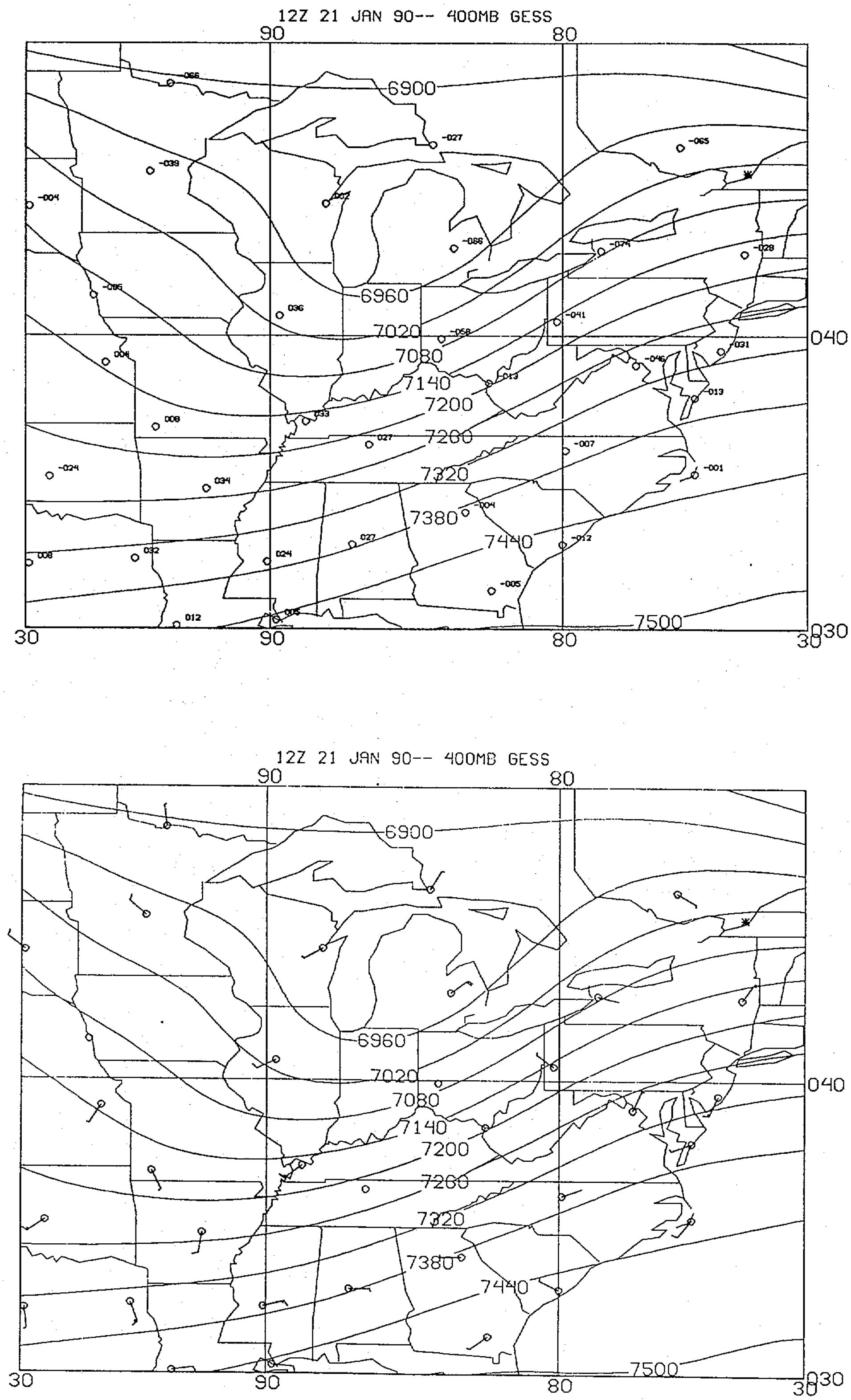
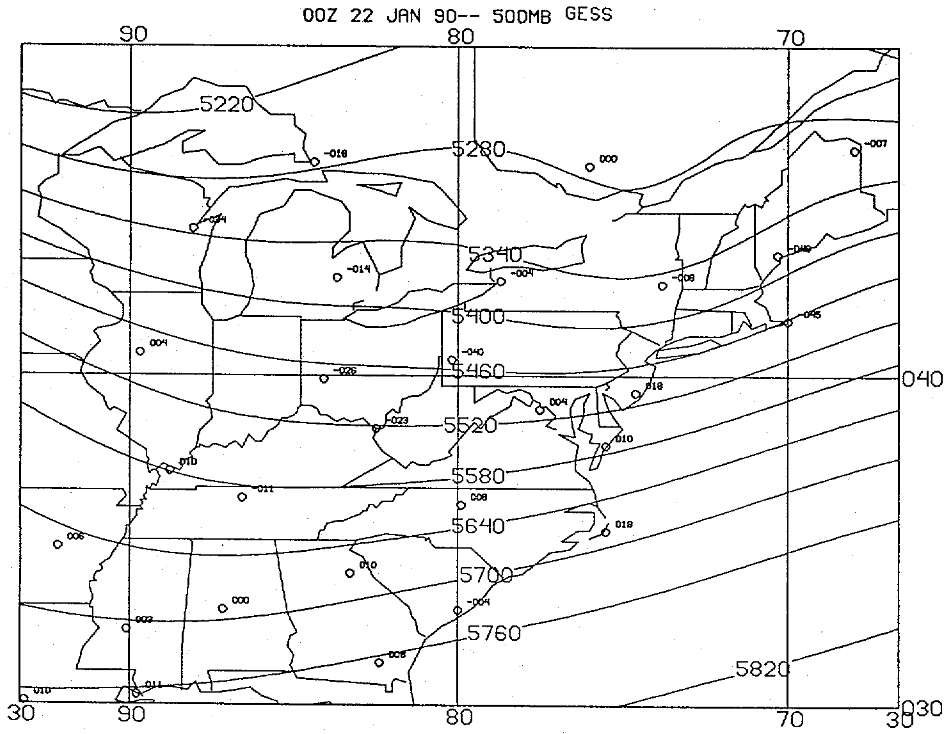


Fig. 37. NMC first-guess 400 mb heights for 1200 GMT 21 January, 1990: (a) with height residuals, (b) with wind residuals.

(a)



(b)

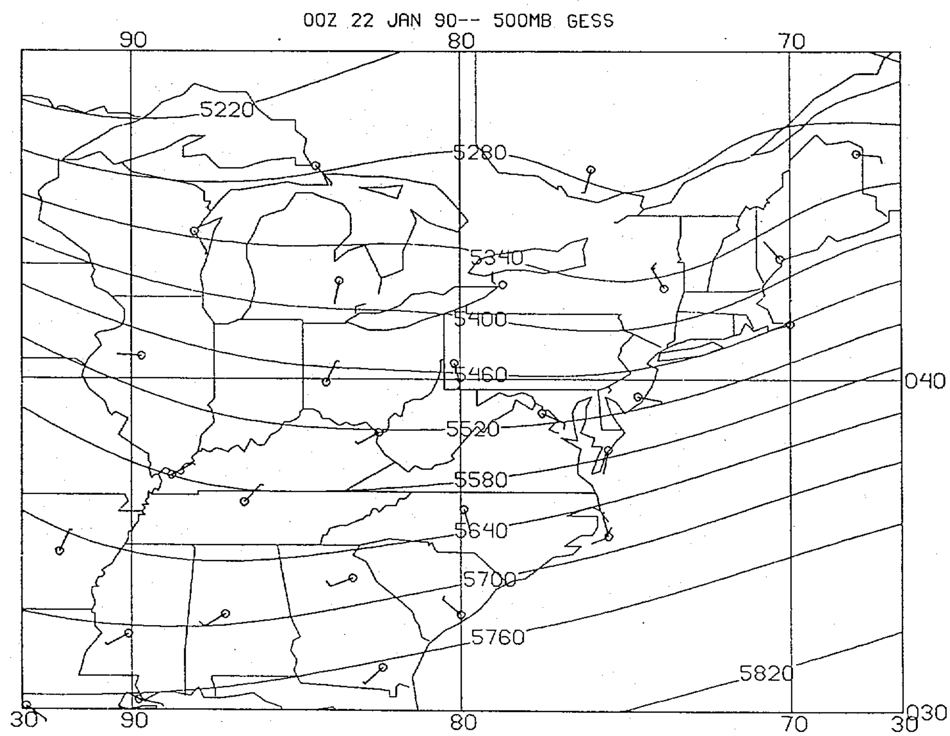
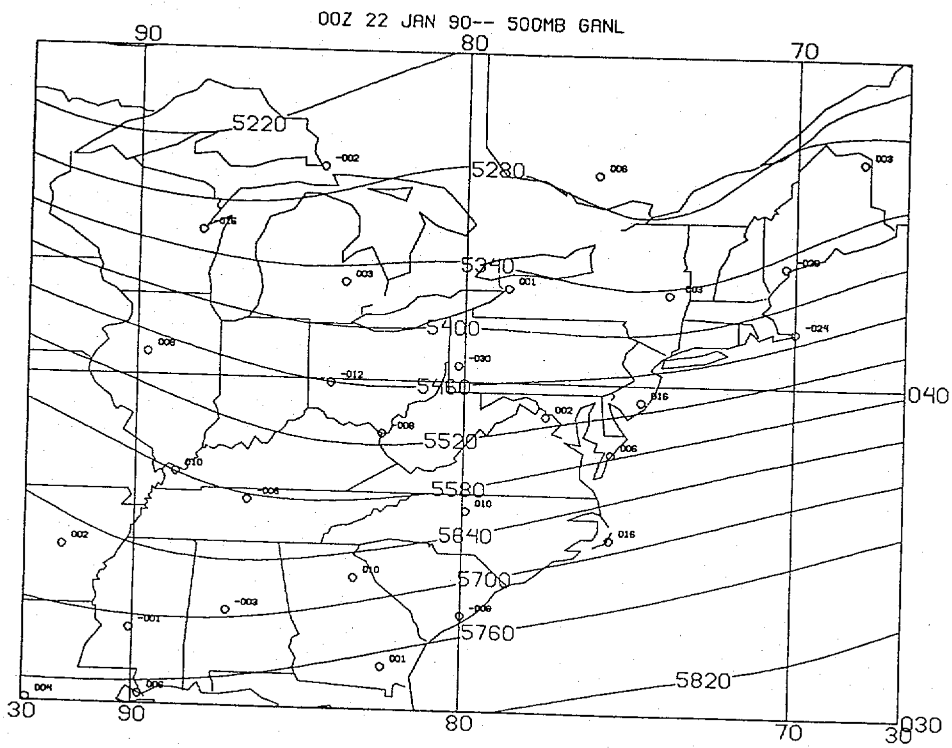


Fig. 38. NMC first-guess 500 mb heights for 0000 GMT 22 January, 1990: (a) with height residuals, (b) with wind residuals.

(a)



(b)

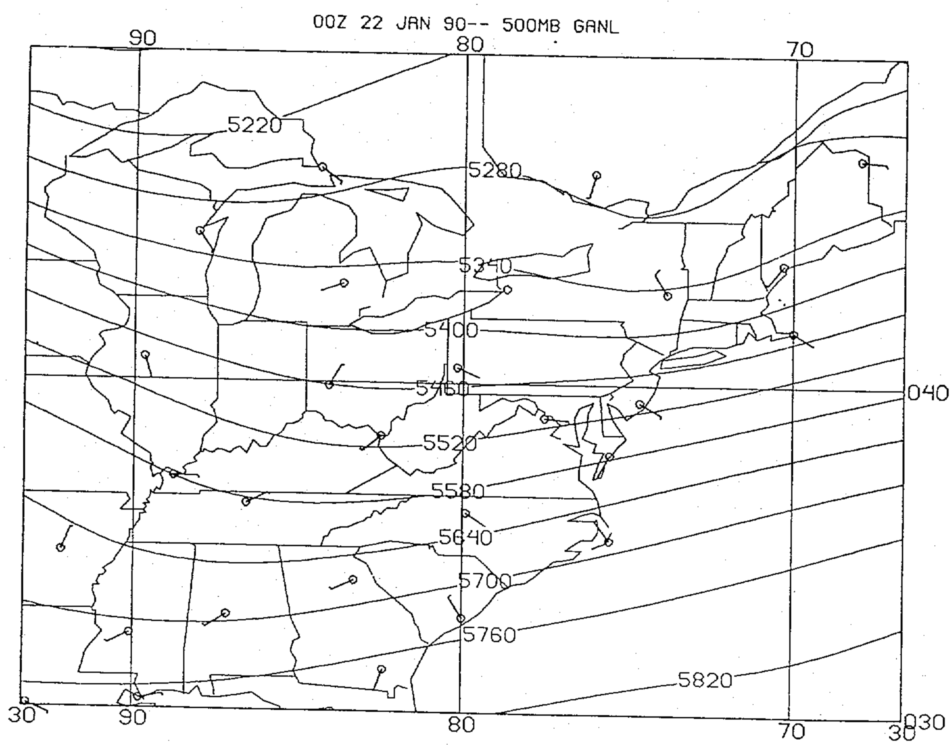


Fig. 39. NMC analysis 500 mb heights for 00Z GMT 22 January, 1990: (a) with height residuals, (b) with wind residuals.

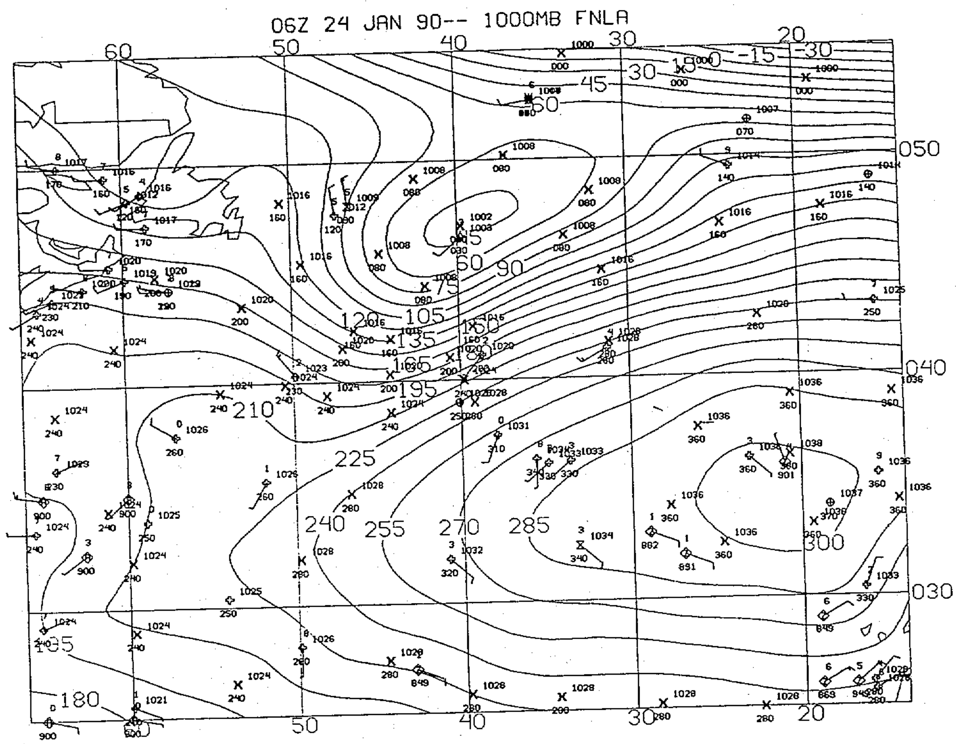


Fig. 40. NMC 1000 mb height analysis for 0600 GMT 24 January, 1990, with surface data overlayed.

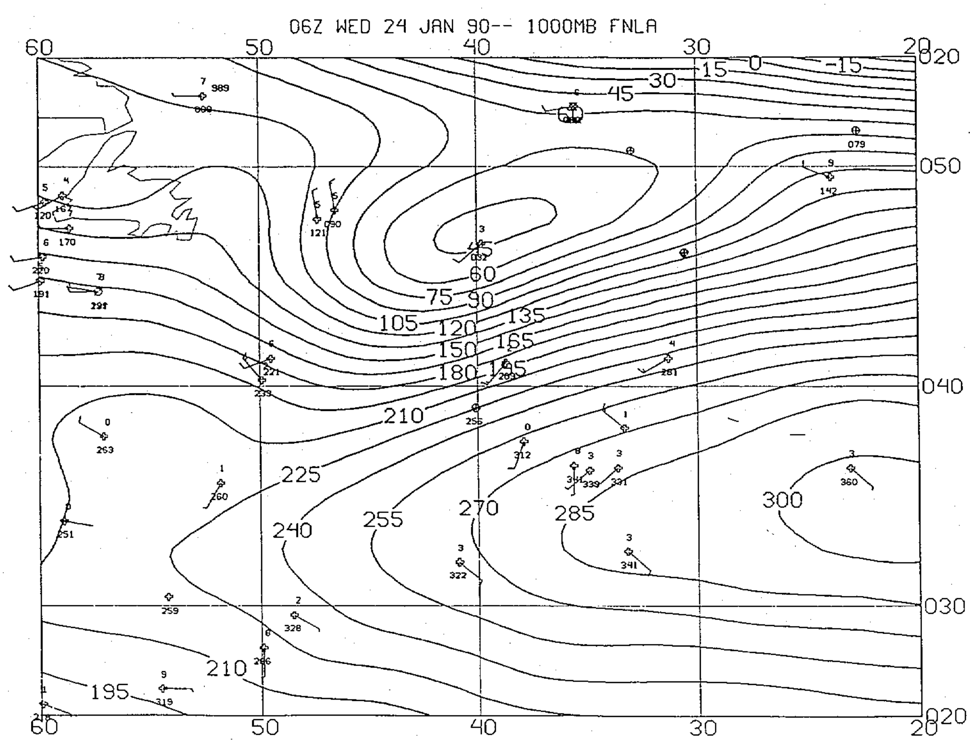


Fig. 41. NMC 1000 mb height analysis for 0600 GMT 24 January, 1990, with raw ship data overlayed.